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International Patent and Patent Family Analysis for Nanotechnology

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Because of nanotechnology's potential to shape a country's future earning power in globally competitive markets, more than 60 countries have adopted national projects or programs to stimulate research and innovation in technology [1]. Both industrialized and developing countries have intensified their nanotechnology R&D efforts of late [2]. Patent analysis can reveal the scope and direction of nanotechnology R&D trends, and has been used, for example, to assess the development of different research communities and technology fields [3, 4]; to study nanotechnology patents published by the US Patent and Trademark Office (USPTO), the European Patent Office (EPO), and the Japan Patent Office (JPO) [5, 6]; and to examine the impact of the US National Science Foundation grants on USPTO nanotechnology patents [7].

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Patents have also been shown to be effective indicators of the R&D status of a given domain. However, because patent documents are stored and maintained by different patent offices (repositories) throughout the world, using data from a single patent office can unevenly represent or under-represent different countries' efforts. This study was devised to examine international inter-repository knowledge sharing and diffusion patterns in nanotechnology, by analyzing patent publication trends from different national/regional repositories with a particular focus on the most active countries and regions.

Data for this study were collected from the *esp@cenet* "Worldwide" database, one of the largest digital repositories of public knowledge in the world [8]. The Worldwide database holds more than 60 million patent documents published by 85 countries/regions' patent offices [9]. Two types of patent rules are used for different countries/regions' patent offices: first-to-invent and first-to-file. First-to-invent means that the inventor who first conceived of the invention and then diligently reduced it to practice by filing a patent application (or actual reduction to practice) is considered the first inventor and is entitled to patent protection. In contrast, first-to-file means that the patent is granted to the inventor who is the first to file a patent application, regardless of the date of invention. Currently, the United States and the Philippines are the only two countries in the world whose patent systems are based on the first-to-invent regime. The rest of the world uses the first-to-file system. The data used in this study were compiled by using a list of nanotechnology keywords to search the titles and abstracts of the patent applications maintained in the database. *Esp@cenet* provides English language translations for most

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of the patent applications published by non-English patent offices. To assess the full range of nanotechnology development since its inception in the late 1970s [5] through now, all relevant patent applications were collected that had been published between 1975 and May 2008 (the time this study began)¹. Patent family information was also collected: patent documents having exactly the same priority or combination of priorities are treated as equivalents that are representative members of a patent family [10].

Statistical Analysis

In total, 54,787 nanotechnology patent applications published in 53 countries/regions' patent offices were collected. More than 98% of the collected applications (53,897) were published by the patent offices of only 15 different countries/regions, each of which had more than 100 nanotechnology patent applications (Table 1). The top four patent offices in terms of the number of nanotechnology patent applications filed were: the United States, the People's Republic of China, Japan, and South Korea. Each of these countries had a substantially larger number of nanotechnology patent applications than other countries (i.e., 17,614; 13,618; 9,680; and 5,078 respectively). (Note: Because the data for 2008 lacks data after May and is therefore not complete, the analysis results presented in this paper are based on patent applications published from 1975 to 2007.) As shown in Figure 1, a sharp upward trend can be seen in the number of applications beginning after

¹ The data fields of patent applications provided by the *esp@cenet* "worldwide" database include: publication number, publication date, inventor name, applicant institution name, applicant country, international patent classification code, European patent classification code, priority number, title, abstract, claim, and description. Among them, the data for applicant country, European patent classification code, claim, and/or description are not complete for some countries/regions' patent offices. As a limitation of the data source, the filing date information is not provided in the *esp@cenet* "worldwide" database. In the future, we will try to leverage other sources to get such information to study and compare the average time it takes in different countries/regions from filing patent applications to being published.

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2001, with the exception of temporary decreases in 2003 for the US and Japan. The PRC's repository surpassed the US' repository in 2006 and 2007, possibly signaling the development of another significant trend in global nanotechnology efforts.

Table 1. Nanotechnology patent applications published in the top 15 countries/regions' patent offices from 1975 to May, 2008.

Rank	Patent Office (Repository)	Number of Nanotechnology Patent Applications
1	United States	17,614
2	People's Rep. of China	13,618
3	Japan	9,680
4	South Korea	5,078
5	Canada	1,448
6	Taiwan	1,360
7	Australia	1,264
8	Germany	1,232
9	Russian Federation	713
10	United Kingdom	561
11	Mexico	383
12	France	379
13	Brazil	254
14	Ukraine	182
15	New Zealand	131

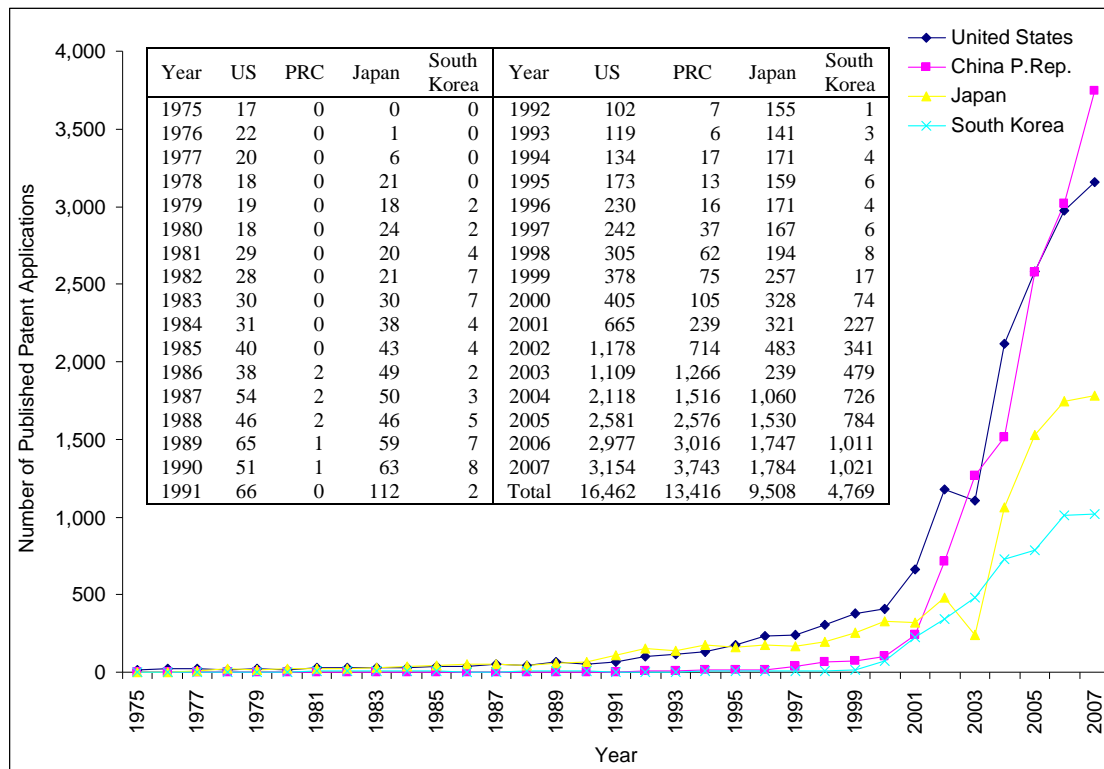


Figure 1. The numbers of nanotechnology patent applications published in the patent offices of the United States, People's Republic of China, Japan, and South Korea by year (1975-2007).

In addition to filing in their own countries, some filers are also active internationally and record their inventions in the patent offices of other countries. The United States was the most internationally active applicant country with the largest number of nanotechnology patent applicants published in different countries/regions' patent offices (Table 2). It ranked first in its own patent office and in those of Canada and Mexico, and second in the patent offices of six other countries, including the PRC and the Russian Federation. Other internationally active applicant countries appearing among the top five in most patent offices include Japan, Germany, South Korea, Taiwan, and France. Despite the level of international activity of some applicant countries, we found nonetheless that the patent offices of many countries still have the largest numbers of nanotechnology patent applications by applicants from within their own countries, indicating a "home

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advantage” effect. The “home advantage” effect is the tendency of domestic applicants to file more patents with their home country patent office than foreign applicants do [11-13]. Ten of the twelve countries/regions’ patent offices listed in Table 2 had the largest numbers of nanotechnology patent applications published by inventors in their home countries.

Table 2. Top five applicant countries in twelve of the top 15 countries/regions’ patent offices (1975-2007). We excluded the patent offices of Japan, Australia, and New Zealand, because the applicant country information of their patent applications is incomplete in the *esp@cenet* “Worldwide” database.

No.	Patent Office (Repository)	Rank	Applicant Country	Number of Nanotechnology Patent Applications
1	United States	1	United States	5,434
		2	Japan	797
		3	Germany	304
		4	Taiwan	302
		5	South Korea	285
2	People’s Rep. of China	1	People’s Rep. of China	11,941
		2	United States	545
		3	South Korea	247
		4	Japan	237
		5	Germany	102
3	South Korea	1	South Korea	3,123
		2	United States	280
		3	Japan	87
		4	Germany	52
		5	France	23
4	Canada	1	United States	674
		2	Canada	164
		3	Germany	106
		4	France	50
		5	Japan	49
5	Taiwan	1	Taiwan	903
		2	United States	224
		3	Japan	113
		4	Germany	35
		5	South Korea	32
6	Germany	1	Germany	1,082
		2	Taiwan	20
		3	United States	18
		4	Japan	14
		4	South Korea	14
7	Russian Federation	1	Russian Federation	209
		2	United States	27

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		3	France	11
		3	Germany	11
		5	Japan	10
8	United Kingdom	1	United Kingdom	136
		2	United States	95
		3	Germany	19
		4	Japan	18
		5	Taiwan	15
9	Mexico	1	United States	224
		2	Germany	25
		3	Mexico	24
		4	France	23
		5	Switzerland	18
10	France	1	France	340
		2	Japan	6
		3	United States	5
		3	Taiwan	5
		5	South Korea	4
11	Brazil	1	Brazil	74
		2	United States	67
		3	Switzerland	17
		3	Germany	17
		5	France	10
12	Ukraine	1	Ukraine	143
		2	Japan	2
		3	United States	1
		3	Switzerland	1
		3	Finland	1

In addition to the top applicant countries, we also analyzed the top applicant institutions in each patent office; these included large companies, universities, and research centers. In the patent offices of the PRC, South Korea, Germany, Russian Federation, France, Brazil, and Ukraine, all of the top five applicant institutions were from the home country. In contrast, all of the top five applicant institutions in Australia's patent office were from the United States. Some internationally active applicant institutions which ranked among the top five in different countries/regions' patent offices included IBM (from the United States), the University California (United States), Samsung Electronics Co. Ltd. (South

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Korea), Hon Hai Precision Industry Co. Ltd. (Taiwan), and Industrial Technology Research Institute (Ind Tech Res Inst; Taiwan).

Topic Analysis

Most patent offices experienced significant increases particularly in 2001 and later. To identify the major research topics driving these upward trends, we conducted topic analysis using the multi-level self-organization map algorithm [14, 15]. Because nanotechnology development expanded dramatically after 2000, we divided the analysis between two time periods: 1975-2000, and 2001-2007. From among the four top ranked patent offices, those of the PRC and South Korea received far fewer nanotechnology patent applications during 1975-2000 than did the offices of the US or Japan.

Accordingly, the research topics were also quite limited relative to the span of time (Table 3). During 2001-2007, however, not only did all four patent offices experience significant increases in the number of nanotechnology patents filed (especially the PRC and South Korea), but there was also an explosion in the number and range of new research topics. Most of these emerging topics related to research tools or methods in physics and electronics; some appeared in multiple patent offices. For example, “semiconductor device” was a new research topic for the patent offices of both the US and South Korea; “carbon nanotube” appeared as a new research topic for both the PRC and South Korea; and “fuel cell” emerged in both the patent offices of the US and Japan. Other new research topics were specific to a particular patent office. For example, “grain fitness” was a new research topic for the PRC’s patent office, and “thermoplastic resin” was a new research topic for Japan’s patent office.

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Table 3. Major research topics in the patent offices of the United States, People’s Rep. of China, Japan and South Korea in two time intervals: 1975-2000, and 2001-2007.

Patent Office (Repository)	Major Research Topics During 1975-2000	Major Research Topics During 2001-2007
United States	Scanning tunneling microscope; Electric field; Laser beam; Ultraviolet radiation; Thin film; Light source; Quantum dot; Atomic force; Aqueous solution	<u>Atomic force microscope</u> ; <u>Semiconductor device</u> ; Semiconductor substrate; Light source; Quantum dot; <u>Fuel cell</u> ; Electric field; Thin film
People’s Rep. of China	Heat treatment; Molecular weight	<u>Carbon nanotube</u> ; <u>Nano material</u> ; <u>Composite material</u> ; <u>High purity</u> ; <u>Grain fitness</u> ; <u>Manufacturing method</u> ; <u>Cathode glass panel</u>
Japan	Scanning tunneling microscope; Quantum dot; Quantum effect; Thin film; Carbon nanotube; Active layer; Gate electrode; Electric field; Electron beam	Atomic force microscope; Thin film; <u>Production method</u> ; <u>Thermoplastic resin</u> ; <u>Fuel cell</u> ; Gate electrode; <u>Metal oxide</u> ; <u>Fine particle</u> ; <u>Carbon nanofiber</u> ; <u>Base material</u>
South Korea	Weight ratio; Fatter ester; Quantum dot	Weight ratio; Quantum dot; <u>Semiconductor device</u> ; <u>Manufacturing method</u> ; <u>Aqueous solution</u> ; <u>Thin film</u> ; <u>Carbon nanotube</u> ; <u>High purify</u> ; <u>Composite material</u>

Note. Underlines indicate new research topics appeared after 2000.

Patent Family Analysis

For each patent office, we identified other patent offices with which it shared the greatest numbers of nanotechnology patent applications. For the United States’ patent office, the largest share (1,152 patent applications) was with Japan’s patent office (Figure 2). The patent offices of the PRC, Japan, and South Korea had their largest shares (599; 1,164; and 573 patent applications respectively) with the United States’ patent office (Figure 2). Most of the other top 15 patent offices (except those of Brazil and New Zealand) also shared the largest numbers of nanotechnology patent applications with the United States’ patent office.

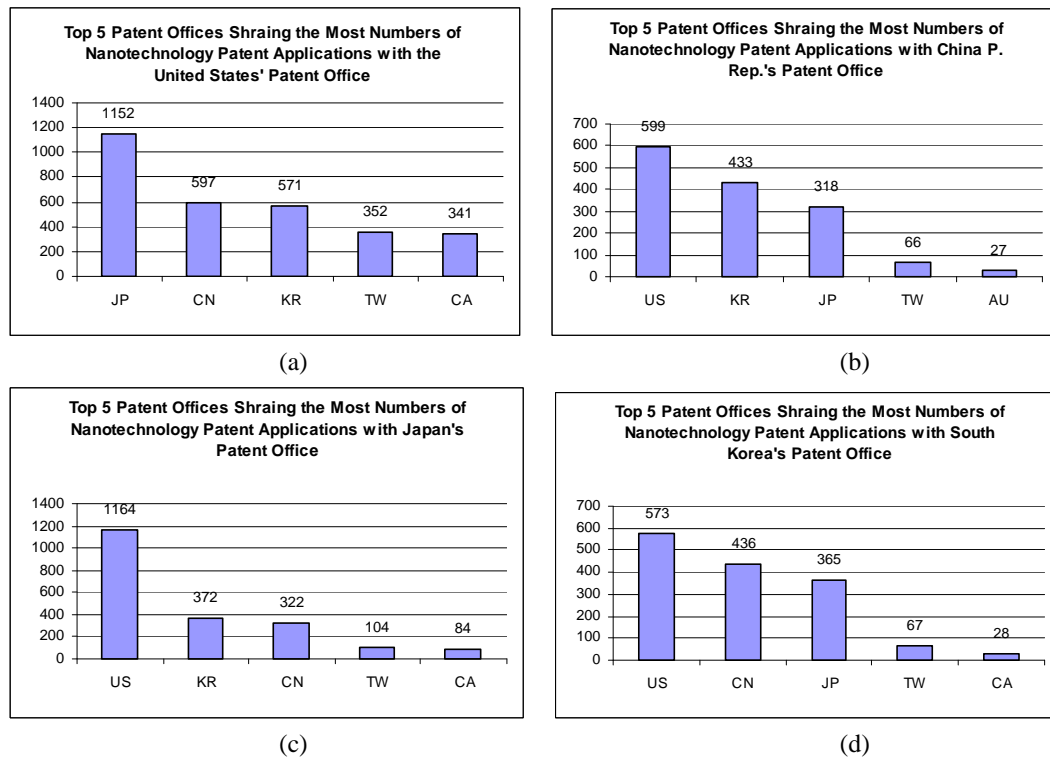


Figure 2. The top five patent offices sharing the greatest numbers of nanotechnology patent applications with the United States', People's Rep. of China's, Japan's, and South Korea's patent offices respectively (2001-2007).

By analyzing patent families across patent offices, we found that each of the top 15 patent offices shared some number of nanotechnology patent applications with other patent offices. The United States' patent office shared the highest number of nanotechnology patent applications with others (2,725), followed by Japan's, PRC's, and South Korea's patent offices (1,457; 1,016; and 974 patent applications respectively; see Figure 3 for the network diagram). In this diagram (drawn using NetDraw, available at: <http://www.analytictech.com/Netdraw/netdraw.htm/>), the nodes represent the patent offices of different countries/regions. The larger the node, the higher the number of nanotechnology patent applications it shares with outside patent offices. The number of nanotechnology patent applications each office shared with others is presented in parentheses after the node label. The link between two patent offices means that they

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have published nanotechnology patent applications in the same patent families. The thicker the link, the greater the number of nanotechnology patent applications the two patent offices shared. The number beside the link indicates how many nanotechnology patent applications the two patent offices shared. The thickest link in the network shows that the United States' and Japan' patent offices shared the largest number of nanotechnology patent applications (i.e., 1,152 patent applications).

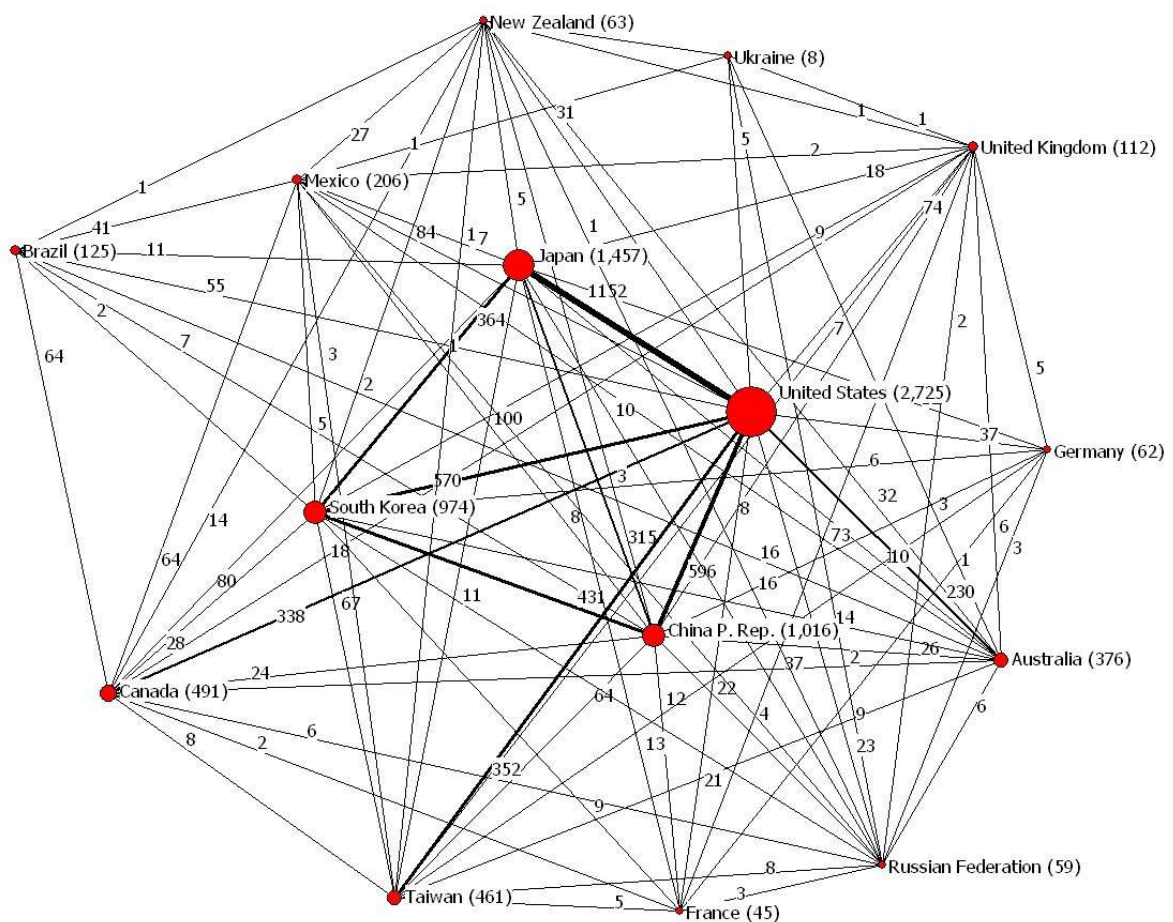


Figure 3. Nanotechnology patent applications shared across the top 15 countries/regions' patent offices (2001-2007).

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Conclusions

Our analysis of patent applications from the *esp@cenet* “Worldwide” database shows the great increase in global nanotechnology R&D output over the past three decades. We identified the top ranking patent offices that have published the largest numbers of nanotechnology patent applications from 1975 on, with the PRC overtaking the US starting in 2006. For each of them, we also identified the top applicant countries and applicant institutions. Significant home advantage effects have been observed in some major patent offices. After 2000, many patent offices experienced a great surge in the number of nanotechnology patent applications, corresponding with the emergence of many new research topics. Patent family analysis results indicated that each of the major patent offices shared nanotechnology patent applications with others, and that many shared the greatest numbers of nanotechnology patent applications with the USPTO. The largest cross-filings between different patent offices was between the patent offices of the US and Japan. Although further efforts are needed for a more detailed picture of the worldwide nanotechnology development, the findings of this study could be a good starting point.

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