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Research on the Evaluation of Nation Nanotechnology Innovation International Level Based on Patent Analysis

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Abstract--**As competition in technology innovation among nations becomes more intense, there is a growing need for improved assessment and analysis method. Patents are the manifestation of the country's technology innovation endeavor; therefore, this paper evaluates the technology innovation international level of the top10 countries ranked by the number of nanotechnology patents. Since the static methodology makes the interpretation of results unclear and makes time series analysis difficult; an improved multi-indicator dynamic comprehensive evaluation method is put forward to establish the evaluation index system. According to the finding from analysis, the evaluated countries are divided into four types: the power, the emerging, the tradition and the weaker. The power should be aware that other countries are gradually narrowing the gap with it. The emerging's performance in patent quality needs further improvement. The tradition is always in the middle level and its development is stable. The weaker can draw on the typical internationalization patterns as the future development path selection. By providing objective insight into the international level evaluation of national nanotechnology innovation through the perspective of patent analysis, this paper hopes to propose some recommendations for future directions.**

I. INTRODUCTION

As an emerging and crossed area, nanotechnology is one of the most rapidly growing and widely affecting scientific and technical fields in the world, especially in the context of pressing global challenges. Organization for Economic Co-operation and Development (OECD) reports suggested that, nanotechnology is not only an important "engine" of social and economic development in the 21st century, but also regarded as the land that contends for surely by developed countries competing for power [12]. On this account, governments around the world have invested heavily in nanotechnology research and development (R&D) and companies are also becoming increasingly engaged. Since nanotechnology is commonly considered to offer considerable promise extending from business opportunities throughout various industries to broader socio-economic benefits, such as those related to energy, health care, clean water and climate change, Lux Research predicted the market share of nanotechnology products by sub-field. Prediction results showed that the contribution of global nanotechnology products on market will reach about $1.5 trillion by 2015. Against this background, the internationalization of nanotechnology innovation is the new trend in national Nano S&T. So there is a growing need for improved judgment and evaluation of nanotechnology innovation international level.

The international level of technology innovation refers to four aspects: the globalization of resource acquisition, the internationalization of creative talents, the networked organization and cutting-edge content. The international level of nanotechnology innovation refers to the current level of nanotechnology accumulation or accomplishment based on past S&T activities. Therefore, the evaluation of nanotechnology innovation international level refers to dynamically evaluating technological innovation capacity and evolution characteristics at an evaluation point. Patent which summarize the achievements of human science and technology and reflects the latest technological inventions as well as the innovative capability of a nation, is one of the important evaluation sources [21]. The statistics of World Intellectual Property Organization (WIPO) showed that, more than 90% of the world's inventions are firstly released as patents and patents contain 90%-95% of R&D endeavor. Accordingly, the effective use of patent indicators can save R & D costs and shorten development time to some extent. Griliches [11] pointed out that patentometrics provides a unique and most effective source for statistical analysis of technological change from detailed industry, organization and technical details, data quality and accessibility, etc., and any other data cannot be comparable with it. On the other hand, the international level of nanotechnology innovation is fundamentally dynamic. However, some conventional methodologies, such as AHP, CCM and so on, are based on static evaluation. The limitation of these methodologies is that there is restraint on the relative expression of level, which makes the interpretation of results unclear and makes time series analysis difficult.

To be specific, this study endeavors to answer the following questions:

1. What are the overall characteristics of global nanotechnology innovation internationalization?
2. How to evaluate the internationalization level of nation nanotechnology innovation accurately, effectively and objective?

In this paper, we firstly review the literature of nanotechnology innovation internationalization, and taking it as logistic starting point, construct the conceptual framework of analysis. Using retrieval strategy, we provide a comprehensive overview of global features through a systematic analysis of patent indicators and statistics. Then, we propose a twice-weighted dynamic comprehensive evaluation method. And this paper includes the evaluation result of top10 countries ranked by the number of nanotechnology patents based on this new methodology. Overall, this study provides an objective reference for future policy directions and academic research in nanotechnology field.

II. LITERATURE REVIEW

Nanotechnology is an interdisciplinary field where dimensions or tolerances in the range 0.1–100 nm play a critical role. Meyer [9] defines nanotechnology as "the manipulation precision placement, measurement, modeling or manufacture of sub-100 nm scale matter". And he [10] on a patent study of nanotechnology suggests that, "the field is misconstrued as either a field of technology or an area of converging technologies while evidence to date suggests its rather that nanoscience and nanotechnology be considered a set of inter-related and overlapping but not necessarily merging technologies". Due to its interdisciplinary and characteristics involving broad areas, a single scientist, organization even country is difficult to promote the development of nanotechnology rapidly and independently, and have to choose the road of technology innovation internationalization. Simultaneously, economic globalization has accelerated the internationalization process of nanotechnology innovation [15]. Internationalization is mainly the way to construct international nanotechnology ties and obtain external nanotechnology. Thus nanotechnology innovation international cooperation has become a topic of keen interest to academics, practitioners, and policy makers. Alan Porter team of Georgia Institute of Technology [8, 13, 20] and Phil team of University of Manchester [14, 15, 16] have done a series of patentometrics studies in nanotechnology field. Researchers have reached the consensus on the role of international cooperation in nanotechnology innovation.

For example, in estimating the effects of international cooperation on the country's nanotechnology innovation, Tang L [17] used a variety of statistical indicators, including research quantity, research quality, cooperation unit and areas distribution, to analyze the status of China in nanotechnology, to summarize Sino-US cooperation mode and dynamic features, finally to study the cooperation impact on the development of Chinese nanotechnology research, founding that the main effect of Sino-US Nano S&T cooperation is improving the quality of research and maintaining China's research in the world frontier. Kay L and Shapira P [7] investigated the Nano S&T development and international cooperation in Argentina, Brazil, Chile and Uruguay, depending on Nano patents and articles. They contended that the Nano S&T cooperation of Latin American nations should be divided into three stages: cooperation within countries, cooperation between countries, and cooperation with Nano S&T powers. They further concluded that four countries have launched substantive research in Nano S&T field respectively, but at different level. Additionally, the degree of commercialization of nanotechnology is still relatively weak. Cunningham S and Werker C [2] explored relationship between Nano S&T cooperation of EU member states and the proximity (organizational proximity, technology proximity and geographic proximity) with a group of data sets containing relevant geographic information. They pointed out that organizational proximity indirectly affects Nano S&T partnership, while technology proximity and geographic proximity affect partnership directly and the influence of geographic proximity is most significant. Guan JC and Ma N [4] applied the bibliometric analysis to the research of Nano S&T international cooperation network between nanotechnology giants, such as China, France, Germany, Japan, and the United States and observed international cooperation has a positive impact on the quality of articles. Even though utilizing different approaches, all of these researches indicate the importance of international cooperation to nanotechnology innovation internationalization; in other word, international cooperation is a significant proxy of technological innovation internationalization.

As time passes and patent accumulates, the evaluation system of nanotechnology innovation international level own a large number of two-dimensional data series by time order. Dynamic comprehensive evaluation, which is a sort of decision-makings, is fit for this dynamic evaluation problem. Dynamic comprehensive evaluation is more complex than static comprehensive evaluation, which is an important branch in comprehensive evaluation. At present, the research has two classifications: One is dynamically adjusting the evaluation index in the comprehensive evaluation processing because of attribute changes; and the other is confirming the evaluation index's weight at different times [1, 5, 6]. Although more and more scholars are focusing on these problems, research results are still rare and there are so many facets in dynamic comprehensive evaluation which need to be further researched and enriched.

III. METHODOLOGY

A. Data

In analysis of nanotechnology innovation internationalization, patents which organizes complex technical information into logical and understandable statistics, is a useful tool. The possession of patents reflects a country's technological innovation capability. Founded in 1802, the United States Patent and Trademark Office (PTO or USPTO) is the federal agency for granting patents and registering trademarks. In the sixth annual meeting of North American Serials Interest Group (NASIG), Narin pointed that patents granted by the USPTO present a relatively accurate picture of the world's technology distribution [11]. Empirical studies proved that, approximately half of patents indexed in the USPTO database are foreign origin and numbers of these patents are roughly proportional to their country's gross domestic product (GDP). Table 1 illustrates the numbers graphically.

TABLE 1 COUNTRIES RANKED BY THE NUMBER OF USPTO-GRANTED PATENTS

Country	Pre 2001	2001-2005	2006-2010	2011-2012	All Years
JAPAN	1	1	1	1	1
GERMANY	2	2	2	2	2
CHINA↓[1]	3	4	5	5	3
TAIWAN↑	8	3	4	4	4
UK↓	5	6	7	8	5
FRANCE↓	4	7	8	7	6
KOREA SOUTH ↑	2	5	3	3	7
CANADA	6	8	6	6	8
ITALY	9	9	9	9	9
SWITZERLAND↓	7	12	12	14	10
NETHERLANDS	11	11	10	11	11
SWEDEN	10	10	14	12	12
AUSTRALIA	13	14	11	13	13
ISRAEL↑	16	13	13	10	14
FINLAND	17	15	15	15	15
BELGIUM↓	14	16	16	16	16
AUSTRIA↓	15	17	17	17	17
DENMARK	18	18	18	18	18

Data compiled by authors for this study

To be specific, the proportion of foreign-owned patent authorization quantity in the USPTO was significantly higher than other four world renowned intellectual property institutions. For example, the foreign-owned patent authorization quantity proportions of USPTO were 50.4% in 2010 and 51.1% in 2011, respectively. Over the same period, the proportions of EPO were 47.2% and 47.5%; those of JPO were 16% and 17%; those of KIPO were 25% and 23.7%; and those of SIPO were 41% and 34.8%. It is the same that the proportion of foreign-owned patent application quantity in the JPO, KIPO and SIPO are far less than that of USPTO. For instance, the foreign-owned patent application quantity proportions of USPTO were 50.6% in 2010 and 50.8% in 2011, respectively. Over the same period, the proportions of EPO were 50.7% and 50%; those of JPO were 15.8% and 16%; those of KIPO were 22.5% and 29.6%; and those of SIPO were 25.1% and 21% [3]. Obviously, compared with other four intellectual property institutions, the USPTO has a higher degree of internationalization. What is more, the USPTO database provides detailed patent cited information which supports the analysis of technological innovation internationalization. Over the years, many academics have carried out a series of research based on USPTO-granted patents that are considered to have higher technological value than foreign patents and can indicate the high quality of invention. From the above, patent data for this study was retrieved from the USPTO database.

B. Retrieval strategy

Currently, the academic community lack of systemic research on search strategy of nanotechnology. In 2004, the USPTO launched a dedicated classification "977" of nanotechnology patent in order to unify the standard. This classification has been recognized and widely used in academia [19]. Thus, we compiled the search query as "ccl/977/$" where "ccl" is the abbreviation of "Current US Classification" and download the patent number online (patft.uspto.gov) by "advanced search" function of the USPTO website. Retrieved content mainly includes following: (1) nanostructures and its chemical composition; (2) devices comprising at least one nanostructure; (3) mathematical algorithms of strategies and properties of nanostructures, such as calculation and software; (4) devices or methods for manufacturing, testing, analyzing, or processing nanostructures; (5) particular purpose of nanostructures. The total number of nano patents retrieved is 9011 on July 31st, 2013, which includes all the US issued patents from 1978 to 2013. Then the patent data was downloaded by HIT software and cleaned up manually.

C. Twice-weighted dynamic comprehensive evaluation method

1) Distinguish variable indicators and stable indicators

Generally speaking, incommensurability exists between different indicators because of their different dimension and magnitude, which brings inconvenience to comprehensive evaluate the indicators' size. For purpose of avoiding unreasonable phenomenon and reflecting the actual situation as much as possible, the dimensionless of indicators is essential which can eliminate the influence of different dimension and magnitude. In this paper, we adopted the extreme value method to achieve the dimensionless of various indicators.

Nano-patent data is a set of planar datasheet sequences arranged by time series, so we supposed that the number of evaluation object is n, i.e. $O=\{o_1,o_2,\cdots,o_n\}$, and the number of indicators is m, i.e. $P=\{p_1,p_2,\cdots,p_m\}$. The indicator value matrix of original indicator set in accordance with the time series i.e. $t = \{t_1, t_2, \cdots t_T\}$ is expressed as:

1 Statistical report released by the USPTO separated the mainland and Hong Kong of China. In order to maintain the consistency of the text, we combined these data in one line.

$$A_t = \left[x_{ijt} \right]_{n\times m} = \begin{bmatrix} x_{11t} & x_{12t} & \cdots & x_{1mt} \\ x_{21t} & x_{22t} & \cdots & x_{2mt} \\ \vdots & \vdots & & \vdots \\ x_{n1t} & x_{n2t} & \cdots & x_{nmt} \end{bmatrix}$$

Assuming that the values of all indicators in set P are extremely large, we make data of matrix A being dimensionless.

$$x_{ijt}^{*} = \frac{x_{ijt} - \min\left\{x_{ijt}\right\}}{\max_i\left\{x_{ijt}\right\} - \min_i\left\{x_{ijt}\right\}}, \quad (i = 1,2,\cdots,n;\ j = 1,2,\cdots,m;\ t = 1,2,\cdots,T) \tag{1}$$

For convenience, the following still remember x_{ijt}^{*} is x_{ijt}.

Taking time series into consideration, the fluctuations of all indicators are different. Some indicators are less volatile, in other words, they are stable in the development of system. Such as number of granted patents, it shows obvious change annual, but the proportion of the total patents in each country exhibits any significant change. Others are variable indicators, such as patent cluster size. Hence, the values of indicators at different times were viewed as different vectors and the angle size between vectors were used to illustrate the fluctuations and thus to distinguish variable indicators and stable indicators. $\cos(p_{ja}, p_{jb})$ is indicated the cosine value of indicator p_j at time a and b. So the fluctuation of indicator p_j is defined as:

$$B_j = \frac{\sum_{a-1}^{T-1}\sum_{b-a+1}^{T}\cos\left\langle p_{ja}, p_{jb}\right\rangle}{\sum_{j-1}^{m}\sum_{a-1}^{T-1}\sum_{b-a+1}^{T}\cos\left\langle \mathrm{p_{ja}}, p_{jb}\right\rangle} \tag{2}$$

Thereby, if the value of B_j is relatively large, the indicator p_j is less volatile, namely a stable indicator. Inversely, if the value of B_j is relatively small, the indicator p_j is a variable indicator. Selecting a suitable threshold α is of great importance to distinguish variable indicators and stable indicators.

$$\begin{cases} B_j \geq \alpha \Rightarrow p_j \cdot is \cdot a \cdot stable \cdot indicator \\ B_j < \alpha \Rightarrow p_j \cdot is \cdot a \cdot \mathrm{var}\,iable \cdot indicator \end{cases} \tag{3}$$

2) Determine weights

After determining the variable indicators and stable indicators, we calculated the weight of different indicators over the years. According to the difference driving principle, the approach to determine the weight coefficient of indicator p_j in year t as follows:

The indicator value matrix of indicator set P related to object set O in year t is expressed as:

$$A_t = \left[x_{ijt} \right]_{n\times m} = \begin{bmatrix} x_{11t} & x_{12t} & \cdots & x_{1mt} \\ x_{21t} & x_{22t} & \cdots & x_{2mt} \\ \vdots & \vdots & & \vdots \\ x_{n1t} & x_{n2t} & \cdots & x_{nmt} \end{bmatrix}$$

Then, the weight of indicator p_j in year t is:

$$\sigma_{jt} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{ijt} - \frac{\sum_{i=1}^{n} x_{ijt}}{n})^2} \tag{4}$$

If the result need to highlight the stable indicators, quadric weighted method is applied to increasing the influence of stable indicators and reducing influence of variable indicators in the evaluation process. The weight of indicator p_j after adjustment is:

$$\omega_{jt} = \frac{\sigma_{jt} \cdot B_j}{\sum_{f=1}^{m}\sigma_{ft} \cdot B_f} (j = 1,2,\cdots,m; t = 1,2,\cdots,T) \tag{5}$$

Similarly, if the variable indicators are highlighted, the weight of indicator p_j after adjustment is:

$$\theta_{jt} = \frac{\sigma_{jt} \cdot \sum_{a=1}^{t-1}\sum_{b=a+1}^{t}\cos\left\langle p_{ja}, p_{jb}\right\rangle}{\sum_{f=1}^{m}\sigma_{ft} \cdot \sum_{a=1}^{t-1}\sum_{b=a+1}^{t}\cos\left\langle p_{ja}, p_{jb}\right\rangle} (j = 1,2,\cdots,m; t = 1,2,\cdots,T) \tag{6}$$

We choose the standard differential to measure the fluctuations of indicators. If the indicator p_j is less volatile, its impact on the results of evaluation is little and its corresponding weight is small, and vice versa. This approach reflects the difference between the evaluated objects from the whole and maximizes the discrimination as much as possible in order to facilitate the sorting.

3) Comprehensive evaluation value

Finally, we gathered all indicators' information using linear weighted model and supposed that the comprehensive evaluation value of object O_i in time t is X_{it}. Then,

$$W_{it} = \omega_{1t}x_{i1t} + \omega_{2t}x_{i2t} + \cdots + \omega_{mt}x_{imt} = \sum_{j=1}^{m}\omega_{jt}x_{ijt} = \omega_t^T x_{it}$$
$$(i = 1,2,3,\cdots,n; t = 1,2,3,\cdots,T) \tag{7}$$
$$x_{it} = (x_{i1t}, x_{i2t}, \cdots, x_{imt})^T,\quad \omega = (\omega_{1t}, \omega_{2t}, \cdots, \omega_{mt})^T$$

This is the result highlighting the effect of stable indicators. Moreover, the result highlighting the effect of variable indicators is below.

$$Y_{it} = \theta_{1t}x_{i1t} + \theta_{2t}x_{i2t} + \cdots + \theta_{mt}x_{imt} = \sum_{j=1}^{m}\theta_{jt}x_{ijt} = \theta_t^T x_{it}$$
$$(i = 1,2,3,\cdots,n; t = 1,2,3,\cdots,T) \tag{8}$$

IV. RESULTS AND DISCUSSION

A. Overview of global nanotechnology innovation internationalization

Patents are an effective and intuitive tool to gauge a country's technological innovation capability. Considering US is major market of China and each country's invention patents in the US are roughly proportional to their country's GDP, the US-granted patents are quite representative of the world's technology. We have selected US patents to research the global nanotechnology innovation internationalization in the present study.

In 1978, M.J. Joy et.al, from Pharmaceutical Society of Victoria, Australia, applied for and obtained the first US-granted nano-patent. Over the years, the applications of nano-patent have a tendency of fluctuation. The numbers of global nanotechnology patents are all less than 10 during the decade from 1978 to 1987. The rapid growth rate after 1988 for nanotechnology patents is very impressive, increasing from 14 to 730 in 2003. However, over the next three years, the total number of nanotechnology patents exhibits a significant decrease. In the 4 years of 2000, 2004, 2005, and 2006, the patents in the world even show negative growth, as depicted in Figure 4. Since 2008 this trend changed and the number of nano-patent reached historic highest in 2012. The statistic of 2013 only counted to 31st July, but the number of nano patents already exceeded two-thirds of the 2012 level, showing good momentum of rise.

Then, we carried out a visualization research of global nanotechnology patents distribution by the geographic information system software, namely Arcgis. We found the hotspot of nanotechnology innovation by observing the shades of color in color blocks.

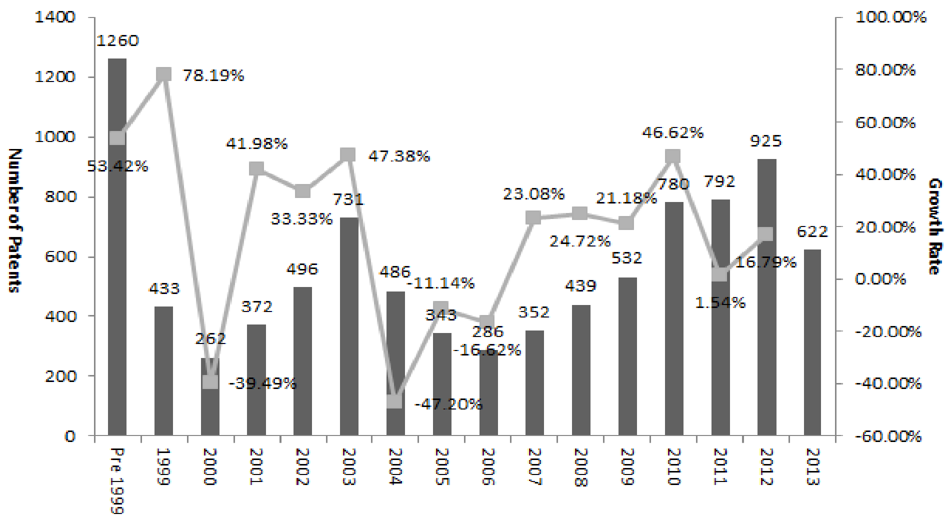

Fig.1 The number of US patents by year

Fig.2 The global distribution of nanotechnology innovation internationalization

The global distribution of nanotechnology innovation internationalization is depicted in Fig.5 and the darker color means the country's nanotechnology innovation capacity is stronger. Nanotechnology innovation powers mainly concentrated in the North America, Western Europe and East Asian countries, where the United States is the most innovative country. In addition to the advantage of the host country, the US policy focusing on innovation is also one of the reasons. Furthermore, the nanotechnology innovation capacities of Western European capitalist powers are also very strong, such as Britain, Germany, and France. Countries in Asia, the number of Japanese patents has ranked second in the world; Republic of Korea developed nano-industry earlier; and China maintains a significant growth of nanotechnology patents. This illustrates nanotechnology distribution from a global perspective, most nanotechnology innovation powers are developed countries.

TABLE 2 COUNTRIES RANKED BY THE NUMBER OF USPTO-GRANTED NANO PATENTS (1978.1.1-2013.7.31)

Country	Records	Rank	Country	Records	Rank
US	5177	1	CANADA	195	6
JAPAN	1403	2	FRANCE	184	7
KOREA SOUTH	572	3	CHINA	180	8
GERMANY	311	4	UK	113	9
TAIWAN	229	5	SWITZERLAND	90	10

Data compiled by authors for this study

In order to select typical countries for the evaluation, the study ranked the countries by the number of US-granted nano-patent since 1978. Due to the USPTO statistical principle base on the country of first inventor [18], the total number of countries obtaining US-granted patents is 72. The innovation advantages of top 10 countries are most prominent, whose total number of US-granted patents accounts for 93.82%. These ten countries and regions in turn are United States, Japan, Republic of Korea, Germany, Taiwan, Canada, France, China, Great Britain and Switzerland, as shown in Table 2.

B. Evaluation index system

To ensure the accuracy and true rationality of evaluation results, four design principles should be noted. First, with the various performance forms of national technological innovation internationalization, both comprehensiveness and importance of the indicators should be taken into consideration. Second, both absolute and relative indicators are essential to the in-depth understanding of technological innovation international level. Absolute indicator, which is the most basic statistical indicator, reflects the overall size or level of the socio-economic phenomena; while relative indicator is the ratio of two related absolute indicators. Third, because international cooperation is the main manifestation of international level and the importance guarantee for improving technological innovation capability, both independent innovation capability and international cooperation capability should be measured. The last but not the least, the aim of this paper is not only to assess the development of nations' nanotechnology innovation internationalization, but also to predict the future trends. So the evaluation index system should include the static indicators and the dynamic indicators.

Accordingly, we established the evaluation index system of nanotechnology innovation international level in the table below.

C. Dynamic comprehensive evaluation results

Based on clear objectives and certain criteria, twice-weighted dynamic comprehensive evaluation method is used to evaluate and quantify the function, quality and attribute, which will be judged valuably. For this research, the technology innovation international level of top10 countries ranked by the number of nanotechnology patents was evaluated. We carried out a dynamic comprehensive evaluation of each nation's nanotechnology innovation international level in accordance with the preceding method. As we mentioned earlier, we chosen threshold $\alpha = 0.1$ to distinguish the variable indicators and stable indicators.

TABLE 3 EVALUATION INDEX SYSTEM OF NANOTECHNOLOGY INNOVATION INTERNATIONAL LEVEL

Primary index	Secondary index	Tertiary index	Codes
Quantity indexes	Absolute indexes	Patent quantity	X1
	Relative indexes	Patent strength	X2
		Patent density	X3
Quality indexes	Citation indexes	Times cited	X4
		Quotation frequency	X5
	Patent coverage degree indexes	patent cluster size	X6
		Patent claims	X7
		IPC classification	X8
	Cooperation indexes	Number of inventors / pc	X9
		Number of Cities / pc	X10
		Number of countries / pc	X11

Data compiled by authors for this study

TABLE 4 INDICATOR TYPE AND WEIGHT

Indicator type	Indicator name	Weight
Stable indicators	Patent quantity	0.118652
	Patent strength	0.107471
	Patent density	0.10873
	Times cited	0.101575
	Quotation frequency	0.077452
	patent cluster size	0.081372
	Number of Cities / pc	0.093888
Variable indicators	Patent claims	0.09169
	IPC classification	0.081416
	Number of inventors / pc	0.078688
	Number of countries / pc	0.059067

Data compiled by authors for this study

Table 4 shows the indicators' types and weights, where only four indicators, that are Patent claims, IPC classification, Number of inventors / pc and Number of countries / pc, are variable indicators. Our next step involves the calculation of the weight of different indicators over the years. If the stable indicators are highlighted, re-weighted method is applied to adjust the indicators' weight.

On the contrary, if the result needs to highlight the variable indicators, the weights of all indicators after adjustment are shown in Table 6.

Likewise, there are two evaluation results of national nanotechnology innovation international level. One is aiming at increasing the impact of stable indicators and reducing impact of variable indicators in the evaluation process and the other one is just the reverse. To facilitate comparison, we normalized two results, as shown in Table 7 and 8.

TABLE 5 ADJUSTED WEIGHTS (HIGHLIGHT STABLE INDICATORS)

Year	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
2003	0.112	0.102	0.118	0.079	0.087	0.099	0.093	0.090	0.077	0.112	0.102
2004	0.112	0.105	0.133	0.077	0.080	0.102	0.082	0.082	0.085	0.112	0.105
2005	0.118	0.126	0.108	0.084	0.076	0.100	0.093	0.068	0.074	0.118	0.126
2006	0.118	0.115	0.135	0.088	0.084	0.089	0.082	0.074	0.069	0.118	0.115
2007	0.114	0.098	0.114	0.065	0.088	0.108	0.083	0.068	0.095	0.114	0.098
2008	0.112	0.109	0.120	0.072	0.083	0.097	0.084	0.081	0.082	0.112	0.109
2009	0.117	0.139	0.131	0.072	0.067	0.100	0.077	0.073	0.073	0.117	0.139
2010	0.112	0.113	0.117	0.071	0.072	0.094	0.100	0.098	0.065	0.112	0.113
2011	0.119	0.110	0.116	0.075	0.092	0.098	0.083	0.088	0.067	0.119	0.110
2012	0.111	0.121	0.127	0.081	0.094	0.092	0.079	0.068	0.065	0.111	0.121

Data compiled by authors for this study

TABLE 6 ADJUSTED WEIGHTS (HIGHLIGHT VARIABLE INDICATORS)

Year	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
2003	0.063	0.070	0.079	0.105	0.105	0.089	0.088	0.108	0.098	0.067	0.127
2004	0.063	0.072	0.089	0.102	0.096	0.092	0.078	0.099	0.109	0.065	0.135
2005	0.067	0.087	0.073	0.112	0.091	0.090	0.088	0.081	0.096	0.070	0.145
2006	0.068	0.081	0.093	0.118	0.103	0.082	0.079	0.091	0.090	0.072	0.123
2007	0.064	0.067	0.076	0.086	0.105	0.097	0.078	0.081	0.120	0.076	0.151
2008	0.063	0.075	0.080	0.095	0.099	0.087	0.079	0.097	0.105	0.075	0.144
2009	0.068	0.098	0.091	0.098	0.082	0.093	0.075	0.090	0.097	0.075	0.133
2010	0.063	0.078	0.078	0.093	0.086	0.084	0.094	0.117	0.083	0.068	0.156
2011	0.067	0.076	0.078	0.100	0.110	0.089	0.079	0.105	0.086	0.069	0.142
2012	0.064	0.085	0.087	0.109	0.115	0.085	0.076	0.083	0.085	0.086	0.123

Data compiled by authors for this study

TABLE 7 EVALUATION RESULTS (HIGHLIGHT STABLE INDICATORS)

Year	US	JP	KR	DE	TW	CA	FR	CN	GB	CH	Mean
2003	0.29	-0.14	-0.18	-0.06	-0.07	0.03	0.02	-0.10	0.09	0.12	0
2004	0.22	-0.05	-0.04	0.03	0.03	-0.07	0.05	-0.04	-0.09	-0.04	0
2005	0.19	-0.04	0.01	0.05	-0.01	-0.05	0.07	-0.14	-0.06	-0.03	-0.001
2006	0.30	0.03	0.09	-0.01	0.06	0.10	-0.10	-0.01	-0.01	-0.44	0.001
2007	0.23	0.08	0.08	0.09	-0.04	-0.18	-0.01	-0.11	-0.04	-0.09	0.001
2008	0.22	-0.02	0.08	0.00	-0.02	0.00	0.13	-0.17	-0.25	0.05	0.002
2009	0.19	-0.04	0.12	-0.04	0.10	-0.01	-0.07	-0.12	-0.04	-0.09	0
2010	0.16	-0.11	0.04	-0.02	-0.02	0.00	0.06	-0.11	0.06	-0.06	0
2011	0.14	-0.09	0.06	0.08	-0.09	0.08	-0.02	-0.11	-0.12	0.08	0.001
2012	0.13	-0.08	0.05	0.01	-0.01	0.07	0.00	-0.11	-0.10	0.05	0.001

Data compiled by authors for this study

TABLE 8 EVALUATION RESULTS (HIGHLIGHT VARIABLE INDICATORS)

Year	US	JP	KR	DE	TW	CA	FR	CN	GB	CH	Mean
2003	0.20	-0.16	-0.22	-0.06	-0.10	0.03	0.04	-0.04	0.15	0.16	0
2004	0.15	-0.08	-0.10	0.08	-0.01	-0.04	0.07	0.07	-0.09	-0.04	0.001
2005	0.11	-0.08	-0.01	0.10	-0.08	-0.01	0.08	-0.09	0.01	-0.04	-0.001
2006	0.23	0.01	0.04	0.02	0.03	0.15	-0.07	0.02	0.03	-0.48	-0.002
2007	0.14	0.10	0.13	0.10	0.01	-0.20	-0.03	-0.07	-0.05	-0.13	0
2008	0.14	-0.05	0.02	0.02	-0.07	0.07	0.21	-0.15	-0.25	0.05	-0.001
2009	0.12	-0.05	0.07	-0.03	0.03	0.02	-0.06	-0.08	-0.02	-0.01	-0.001
2010	0.07	-0.13	-0.04	-0.02	-0.06	0.08	0.10	-0.08	0.09	0.00	0.001
2011	0.08	-0.11	-0.03	0.12	-0.14	0.14	-0.02	-0.08	-0.12	0.15	-0.001
2012	0.07	-0.09	-0.02	0.04	-0.07	0.14	-0.01	-0.05	-0.06	0.06	0.001

Data compiled by authors for this study

According to the tables above, we got the final evaluation scores of nanotechnology innovation international level of top 10 countries during the period from 2003 to 2012. For a more intuitive display of changes in each year, we subtracted the mean from the value of each year. If the result is a positive value indicating that the international level of this country's nanotechnology innovation is higher than average. Among the top 10 leading countries, the one with the highest score of nanotechnology innovation international level is the United States, which means that its innovation capability has been the top in nanotechnology field. A closer look into the value of US reveals that the nanotechnology innovation international level of US is always above average and the overall nanotechnology innovation international level in the top 10 countries is not so balanced.

V. CONCLUSION

Nanotechnology evaluation based on the twice-weighted dynamic comprehensive evaluation method leads to an evaluation of the international level of technological innovation, and this evaluation can be used to identify the technological status of nations. Furthermore, this methodology makes it possible to provide the static data necessary for understanding global nanotechnology and establishing an index system for evaluating each country's nanotechnology innovation capability. In addition, it facilitates the establishment of strategies for catching up world leaders by predicting potential technology trends and the pace of technology development. The major result of this research is the comprehensive evaluation value of technological innovation international level of top 10 countries in nanotechnology field. We selected the data in the 3 years of 2003, 2007, and 2012 to reflect the trend for nearly ten years with the stable indicator's values as X-axis and variable indicator's values as Y-axis. Therefore, if one country's comprehensive evaluation value is in the positive axis indicating that the nanotechnology innovation international level of this country is higher than average.

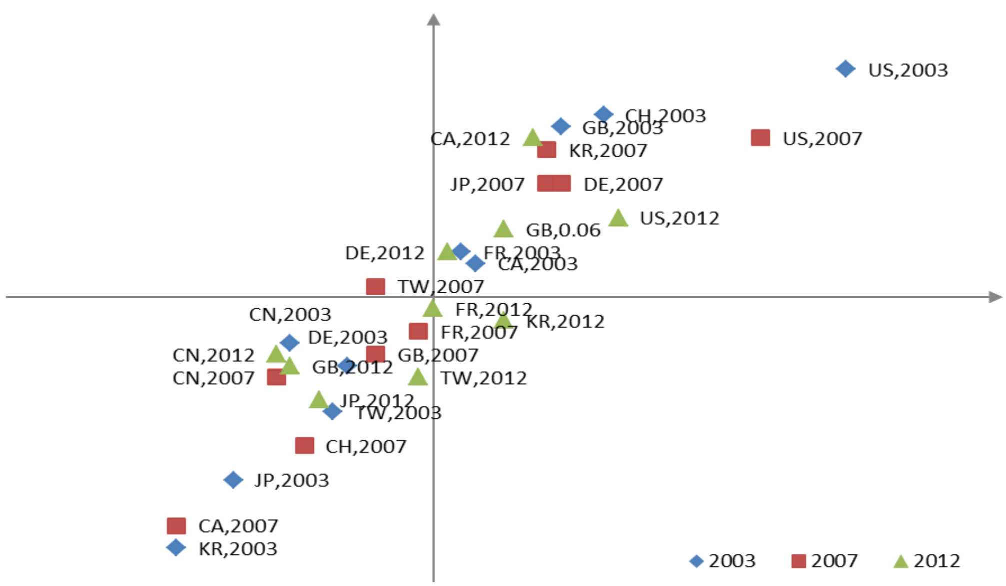

Fig.3 The changes of ten countries' comprehensive evaluation value by year

From the chart, these ten countries can be divided into four types:

(1) The power. The nanotechnology innovation level of the United States, as representative of the nanotechnology power, has been higher than that of other countries. It illustrates that from the global perspective, the federal government have become so focused on technology R&D and innovation activities that nanotechnology is bound to maintain its leading position in the global nanotechnology structure. However, it is easy to see that the United States exhibited slight declining trend and its innovation advantage is more and more small. Although the United States remain in the first quadrant, other countries are gradually narrowing the gap with it.

(2) The emerging. Republic of Korea and Taiwan are the representatives of the emerging nanotechnology innovation countries and regions. From the early days, they devoted themselves to nano science and technology research, and at the same time they carried out the layout of nano S&T. So that these two countries have nanotechnology advantages base on the early basic research. Despite Taiwan is always in the third quadrant, its nanotechnology maintains a rapid growth trend. The technological innovation capability of Republic of Korea has improved most rapidly during the past 10 years, but its performance in nano-patent quality has not been outstanding and still needs further improvement.

(3) The tradition. As the representatives of traditional nanotechnology powers, France and Germany have always been in the vicinity of the origin, proving that they are in the middle level and their development is stable. For instance, the number of German nano-patent is less than that of Japan, while its comprehensive evaluation value highlighting the patent quality is in a leading position.

(4) The weaker. China can be seen as an example herein. China is one of the earliest countries to conduct nanotechnology research and playing a more active role in the word. In recent years, a series of nanotechnology breakthroughs have been made by Chinese researchers, meanwhile the total number of Chinese nanoscience papers ranks first. Despite the advantage of basic research in nanotechnology, China’s technical innovation capacity is still poor compared to other nine countries or regions, and there exist an apparent large gap between China and the United States though this empirical study. Therefore, in the process of enhancing nanotechnology’s comprehensive strength and competitiveness, the internationalization’s role of technology innovation and basic research are equally important. Only communicating and cooperating with different economies deeply and extensively, can a country maintain more lasting innovation vitality in nanotechnology.

In conclusion, the international level of nanotechnology innovation has been explored through the patent analysis, in hope of providing an objective statistic reference for future policy directions and academic researches. Each nation follows a different international pattern of nanotechnology innovation because of such as professional human resources, investment levels and infrastructure, differ among nations. Hence, one must develop a future path of nanotechnology innovation internationalization taking into account the characteristics of each nation's nanotechnology and develop strategies that are tailored to each nation's technological development. For instance, when we study Chinese nanotechnology innovation internationalization mode, not only do we analyze our existing mode, but also carry out comparative study in order to look at the typical nations. Such as, the United States has the largest number of nano patents; Japan is the country with the highest centrality; and Germany’s independent innovation capability is relatively strong. Meanwhile, the U.S., Japan and Germany, respectively, are on behalf of North American countries, Asian countries and European countries. So choosing these countries as a control group to find out the similarities and differences of nanotechnology innovation internationalization mode between China and them and provide the basis for China’s path selection is a possible area for our future research.

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