Two Poles in Global Nano Research: Structure and Evolution of the Global Nano Collaborative Innovation Network

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***Abstract*--Nano Science and Technology (S&T) is one of the core areas of S&T competition among developed countries in the 21st century and plays a supporting and leading role in social, economic and technological development. As an emerging international interdisciplinary subject, cooperation is of great significance to the development of Nano S&T. Current studies of international Nano S&T cooperation focus mainly on cooperation between countries [1-3] without much contribution to the understanding of these global networks at a global level. Based on the Web of Science (WOS) database, this paper presents a bibliometric, statistical and social network analysis to: (1) characterize the overall status of Nano Collaborative Innovation Network (NCIN); (2) identify core and periphery countries; (3) analyze the evolution and characteristics of each node of NCIN; (4) evaluate the scientific publication output quality of each country from NCIN and analyze research hotspot changes of NCIN; and (5) visualize the NCIN network. A more detailed look at China in this NCIN provides support for improving the research quality and international influence of China's Nano S&T.**

I. INTRODUCTION

Nano Science and Technology(S&T) is one of the core areas of S&T competition among developed countries in the 21st century and plays a supporting and leading role in social, economic and technological development. In 2000, the United States launched its National Nanotechnology Initiative [34], which was followed by increasing Nano S&T research around the world, with many nations setting targets for Nano S&T. By 2012, more than 60 countries have released Nano S&T support plan [7]. As an emerging international interdisciplinary subject, Nano S&T plan of most countries stress on strengthening international cooperation in S&T for the development of nanotechnology. China is also one of the earliest countries to carry out research in Nano S&T and has made great progress. The "twelfth five-year" special planning of national major scientific research in Nano released by the Ministry of Science emphasis that China seeks to promote the internationalization of Nano S&T innovation process, encourage international cooperation project to strengthen international cooperation and improve the overall level of Nano S&T.

International cooperation is of great significance to the development of Nano S&T. According to the statistical results of published international cooperative papers of SCI, the amount of China's international Nano cooperative papers ranked second in 2010, exceeding Germany and coming close to the US. Current studies of global Nano Collaborative Innovation Network (NCIN) are few, mainly including Kay L and Philip[13], Philip and Li Tang [30], Guan Jiancheng [10], Shi Yuan[27], Ye Xuanting[33], who base on bibliometrics methods, analyze network characteristic of Nano S&T cooperation between countries, lacking overall characteristics of global Nano S&T. Thus this paper draws on a Web of Science (WOS) database, to develop a retrieval strategy, develop a dataset, and analyze the overall status of Nano Collaborative Innovation Network (NCIN) using bibliometric and statistical methods. We use Gini coefficient to distinguish uneven distribution in cooperation; a core-periphery distribution analysis to identify core and periphery countries and their evolution in the network; Centrality Indexes to analyze the evolution characteristics of each node of NCIN; bibliometric indicators to evaluate quality of each country's Nano publication outputs and hotspot changes of international Nano cooperative papers; and, finally, a visualization method to display and map the NCIN. Through this approach, we analyze the structure and evolution characteristics of NCIN, further grasp the orientation and characteristics of China in this NCIN and provide support for improving the research quality and international influence of China's Nano S&T.

This paper is organized as follows. Section 2 presents an overview of related research in international Nano S&T cooperation. Section 3 the methodology. In the last section, conclusion remarks are provided. Section 5 summarizes findings and presents our next steps in this work.

II. BACKGROUND

Collaborative research is a key mechanism to promote the spread of knowledge production in science and technology field. For nearly 30 years, great changes of organizational structure in scientific research environment have made the scientific community pay more attention to promote international cooperation. As a new and fast emerging field, Nano S&T involves several disciplines and research areas such as physical chemistry, condensed matter physics, biochemical engineering, polymer science, environmental sensing, and quantum computing and so on. Due to this, science and technology cooperation is very conducive to the future development of Nano S&T.

Nowadays, research about Nano S&T international cooperation focuses on the following four aspects: (1) cooperation between Nano S&T countries; (2) cooperation between Nano S&T institutions and interdisciplinary; (3) association between nanoscience and nanotechnology; (4) collaborative research methods and retrieval strategies of Nano S&T Thesis.

A. Nano S&T countries cooperation research

Economic globalization has accelerated the internationalization process of nanoscience innovation activities and Nano S&T [26]. Studying and analyzing Nano S&T inter-country cooperation model, such as Sino-US, EU, developing countries etc. has gained a big momentum, resulting in an increase of research in the related fields.

Tang L et al. has launched a series of in-depth research on Sino-US Nano S&T cooperation. In the aspect of scientific research cooperation pattern and dynamic tendency, Tang L [30] 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. R Kostoff [15] made a comparative analysis of China and the U.S. Nano S&T outputs which is based on WOS database. The result showed that Chinese Nano S&T production in 2011 had surpassed American in accordance with the predicted curve of 2009, and this is statistically significant (over 20%). For instance, the growth rate of China's articles on Nano-composite materials has reached more than twice that of all articles in three years, and the trend is not slowing down.

Cunningham S and Werker C [4] 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. Carayol and Matt established a regression analysis model for all disciplines of Nano S&T cooperation pattern according to the universities' public reports and described the international cooperation characteristics of French university laboratory. Up to now, the cooperation between EU member states and the rest of the world in the field of Nano S&T has been involved all related industry.

China makes great efforts to promote Nano S&T research, which can be traced back to the decade "climbing" program launched by the ministry of science in 1990. Guan JC and Ma N [10] 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. Ye XT [33] presented the international cooperation pattern of China's Nano S&T articles. As another developing country, India's Nano S&T are advancing rapidly. Karpagam etc. [12] analyzed the growth pattern of India's Nano S&T articles for nearly 20 years. The study based on Scopus international interdisciplinary literature database and employed a range of indicators including national Nano-paper annual growth rates, co-author mode, cooperative metric, synergistic coefficient, disciplines distribution and other indicators [12]. Bhattacharya and Nath collected the patent grant data from the United States Patent and Trademark Office (US-PTO) to compare China's and India's technology impact. Liu et al. compares the trends for Nano S&T development of papers and patents in China, Russia and India using SCI papers and USPTO patents database.

Meanwhile, a small fraction of this attention has been spent understanding Nano S&T cooperation among other developing countries. Kay L and Shapira P [14] 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.

B. Nano S&T institutions and interdisciplinary cooperation research

Interdisciplinary is the key nature of nanoscience. On one hand, nanoscience is the result of intersection and integration of different disciplines; on the other hand, it also affects the development of other disciplines. Industrial sectors such as aerospace, biotech, energy, physics, chemistry, etc. depend on materials and device made up of atoms and molecules, by default can all be improved by application of nanoscience and nanotechnology [12]. J Corbett et al. [5] combed the evolution of Nano S&T, discussed the nature of interdisciplinary, compared the scale of government investment, and finally predicted the impact on the field of biology, nano-device, materials, precision engineering, etc. Bassecoulard et al. [2] mapped the citation flows of nanotechnology publications, classified papers into the clusters and showed that the themes uncovered are moderately multidisciplinary. Studies of relevant publications continue to demonstrate that nanoscience is drawing on and contributing to multiple areas of science.

Meyer and Persson [20] made clear the interdisciplinary nature of nanotechnology and also looked at differences among countries during the period 1991–1996. Schummer

[25] analyzed the development of scientists and engineers in 600 published papers of eight existing journals in 2002 and 2003, and also investigated multidisciplinarity and interdisciplinarity research collaboration in current nanoscale research. It turned out that degree of interdisciplinary is on average but high degree of multidisciplinarity. Leydesdorff [17] examined 12 journals and indicated them as developing interdisciplinarily at the interfaces between applied physics, chemistry, and the life sciences.

C. Research on relationship between nanoscience and nanotechnology

Meyer [19] explores the relationship between Nano S&T papers and patents in three European countries that are Britain, Germany and Belgium, and then proposed the following research question: whether the achievements of author who published paper and patent simultaneously become more prominent in number and cited frequency? The results showed that authors who published both papers and patents are superior to them who only published papers in the quantity of output and cited frequency. But the list of highly cited authors does not contain patent inventors, these indicating that patent activity does not have a negative impact on the publication of paper, nor a strong correlation.

Kostoff [16] et al. conducted the text mining research on nanoscience and nanotechnology using SCI/SSCI database in order to discovery (1) prolific authors, core journals / institutions / countries, the highest cited author / journal / article; (2) nanotechnology structure; (3) nanotechnology equipment; (4) potential technical applications; (5) health effects; (6) the groundbreaking nanotechnology literature.

D. Collaborative research methods and retrieval strategies of Nano S&T thesis

Scientometrics is usually defined as the quantitative studies of science and technology, including all quantitative aspects of scientific nature in science and science policy [32]. Draw maps in scientometrics is a relatively common method, which uses visualization to display network structure [21]. Data visualization is the study of visual representation of data, social network visualization technology can efficiently reflect and reveal complex relationship in social networks and their change rules and help people deepen the understanding of the social network structure and communication [9].

Through literature research, scholars have proposed many definitions of Nano publication retrieval strategies, which can be concluded as three types: Vocabulary Query and Improvement, Citation Analysis, Nano Core Journals.

(1) Vocabulary Query and Improvement: Porter first raised retrieval strategy based on vocabulary query, which directly uses the keywords for query, whose implementation is relatively clear and steps are relatively simple. In vocabulary query, we reference experts' idea to identify keywords [24]. Mogoutov and Kahane take automated query methods, use the still word "Nano *" as a keyword for query, in combination with automatically generated specific subject keywords and experts' suggestion to determine retrieval strategy [22]. Arora et al proposed improved vocabulary query method in 2012, which characterized by mutual inspiration between experts and keywords and establishing effective feedback channel [1].

(2) Citation analysis: Retrieval strategy based on citation analysis is dependent on a set of core literature to identify the core cited article. Accurate parameters of the algorithm are defined and constraint by the author who implements the strategy. Therefore, compared with vocabulary queries, retrieval strategy based on citation analysis doesn't need to be experts' inputs. Through a series of nanotechnology literature from modular query, Zitt and Bassecoulard use citation network to extend the Nano S&T thesis database [35]. Through confirmation of key articles, citation analysis method determines the algorithm to carry out automatic citation analysis, and relies on few parameters that can be configured to keep papers that have important reference relationship with core papers. Drawback of citation analysis is that how to determine the seed document and how to remove irrelevant articles.

(3) Nano core journal retrieval: Leydesdorff and Zhou put forward a method, start from the core set of 6 nanotechnology journals, through citation and network analysis, and extend the core set to 10 journals. The standard of determining core periodical is that the title of the journal contains at least "Nano" [18]. Huang and other studies have found that, although in theory, periodicals method has higher accuracy, but the width is not enough, because the scope of nanotechnology research publications exceeds far beyond the scope of the professional journal of nanotechnology [4]. Discipline classification basis of WOS is also based on the core journal retrieval WOS includes 249 subject classifications such as Acoustics, in which 164 class are Nanoscience and Nanotechnology, under which there are 70 SCI journals in the field of Nanotechnology. According to Bradford literature law, the total paper identified by Nano core journal accounts for about 30% of all Nano papers.

Determination of retrieval strategy is the basis of the study, with a strong goal orientation; different analysis purposes have different focus on literature retrieval standard. Based on the requirement of research, retrieval strategy in this paper should have the following four characteristics: (1) coverage, we require the retrieve results can cover all the data required by nanotechnology in the WOS database; (2) the accuracy, we need the retrieval results can reach the highest precision and have less data redundancy; (3) the rationality, we require each step is justified; (4) independence, we require that retrieval strategy is not dependent on other keywords. Three kinds of retrieval strategy comparison results shown in the table 1.

TAB.1 COMPARISON BETWEEN THREE RETRIEVAL STRATEGIES

Retrieval strategies	Representative scholars/organizations	Spreadability	Accuracy	Rationality	Independency
Vocabulary Query and Improvement	Mogoutov,Kahane etc.; Porter etc.; Aroraa etc.	Broad	High	Good	Poor(heavily rely on expert competencies)
Citation Analysis	Zitt、Bassecoulard etc;	Broad	Low	Medium	Poor(rely on accuracy of seed documents)
Nano Core Journal	Leydesdorff、 Zhou; WOS database	Narrow	High	Good	Good

As it's showed in Tab.1, among the three retrieval strategies, Vocabulary Query and Improvement method has the widest coverage, higher accuracy and less data redundancy, and each step of it is reasonable, but its independence is poor and rely on the determination of seed literature; Nano Core Journal has the highest, no data redundancy and good independency. It doesn't rely on experts' judgments and seed literature. But its coverage is not good. To sum up, in view of the research object and purpose, vocabulary query method is the most reasonable and effective of the three kinds of retrieval strategy. So in this article, we adopt the latest retrieval strategies raised by Arora et al [1], improve the second stage of noise removal for retrieval, and build data base for the retrieval results.

III. DATA COLLECTION AND RESEARCH METHODS

A. Data collection

1) Data download

Based on the improved word frequency query method of, according to the retrieval determined by Aroraa etc. (retrieval as appendix 1), the time is defined from 2003 to 2012, 696909 articles of raw data are downloaded from WOS. The data is imported to VantagePoint software, considering the processing conditions of the software (no larger than 2 Gb of memory), take a year as an unit from 2003 to 2006, half a year as an unit from 2007 to 2010, four months as an unit from 2011 to 2012 to create Nano paper database, which are divided into 18 VP data files.

2) Data cleaning

The software is mainly used for cleaning articles whose title contains "Nano *", but whose content has nothing to do with the Nano S&T, such as NaNO3 (sodium nitrate), Nanoliter (liters). The cleaning is divided into two classes, the first is that papers whose title includes Nano should be removed, such as papers whose title contains vocabulary like plankton are removed; The second type is to remove paper whose title only contains only the word. For example, papers whose title only includes vocabulary "Nano – second", but no other keywords related to the Nano should be removed. After cleaning up, the total data is 650367.

3) Data extraction and database building

Based on the data being cleaned up, we define papers whose authors' nationalities equal or are more than 2 as cooperative papers. Extract them and establish paper database whose amount is 144625 and accounts for 22.24% of Nano database after cleaning, and each year the cooperation ratio is about 22%; we define papers whose authors' nationalities equal or are more than 3 as highly cooperative paper database(accounts for about 20% of cooperative papers).

B. Research methods

Bibliometrics analysis is a set method for quantitative analysis of S&T literature which is widely applied in many areas to evaluate the impact of a specific article, a group of researchers or a research field [23]. Social network analysis is a set of specifications and methods for analyzing structure and attributes of social relations. It mainly analyzes the structure and properties of different social units (individuals, groups, or social) relationship [23]. In this paper, using research methods of bibliometrics, we carries out bibliometrics analysis of Nano S&T cooperation, expecting to provide valuable quantitative information for research and development in Nano S&T. We use social network analysis method; based on paper cooperation network between countries extracted from VantagePoint software's matrix function, carry out the centrality analysis, core marginal distribution analysis, to grasp the present situation and characteristics of global Nano S&T collaborative innovation networks, analyzes the status and characteristics of us in Nano S&T cooperation network. In this paper, we use software including measuring literature and patents bibliometrics tool-- VantagePoint, social network analysis tool—UCINET and visualization tools-- Pajek and Gephi.

IV. RESEARCH RESULTS

A. Overall status of global Nano S&T innovation cooperation network

As an emerging interdisciplinary discipline, almost all of the countries that carried out Nano S&T plans will strengthen international S&T cooperation in future Nano S&T development layout. The amount of international Nano cooperative papers accounts for 22.24% of Nano S&T papers.

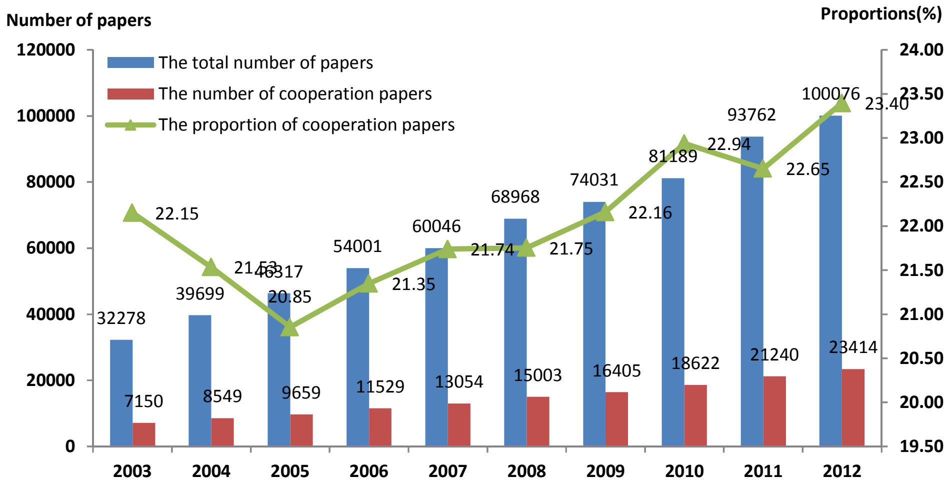

Fig.1 The proportion of international nano cooperative papers of total papers

TAB.2 CHANGES OF BILATERAL RELATIONS NUMBER IN INTERNATIONAL NANOS&T COOPERATION

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Bilateral relations number	896	1003	1058	1141	1651	1355	1453	1606	1709	1826

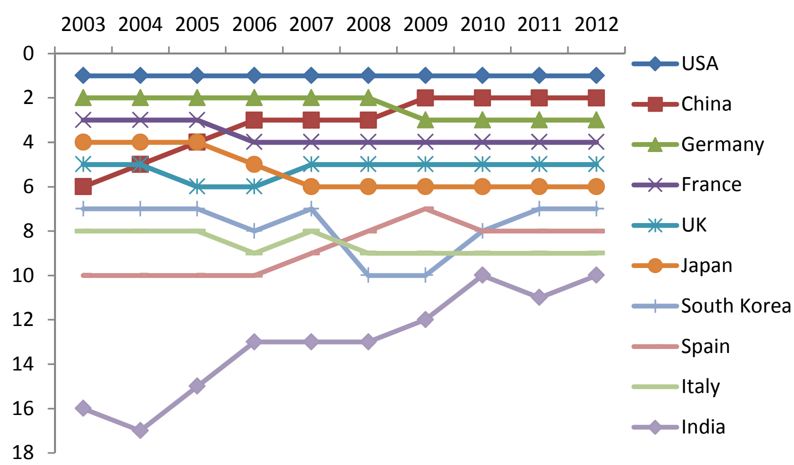

Fig.2 Quantity order change of international nano cooperative paper of Top 10 nations

As is shown in Fig.1, the number of Nano publications keeps steady growth from 2003 to 2012. Compared with 2003 papers, Nano paper volumes increased by 210.04%.in 10 years, in which the ratio of international Nano cooperative papers to total papers remained near 22%. Countries that participate in international cooperation also presents overall rapid growth trend, rose from 102 countries in 2003 to 131 countries in 2012, reaching its peak in 2011 for 138 countries, the average annual growth rate is 2.81%. The bilateral relationship number in international cooperation refers to how many pairs of countries established cooperative relationship. The following table 1 reflects changes in bilateral relation number in international Nano S&T cooperation. As is shown in the table, in 2012, 1826 pairs of countries established bilateral relations of Nano S&T paper cooperation, which more than doubling in 2003.

As is shown in Fig. 2, as the economic and technological power, the United States, Japan and Europe have been in a dominant position in international S&T cooperative network. Among other Asian countries, South Korea starts Nano layout relatively early, from the perspective of national strategy, attaches importance to the development of Nano S&T, and from 1990 s, started the Nano S&T research and development, so ranks in the front in international Nano cooperative papers. In addition, in the top 10 countries in 2012, most obvious upward trend was seen in China and India. Number of international Nano cooperative papers of China jumped from the sixth to the second, narrowing the gap between it and the United States; while that of India gradually increased from the 18th and jumped into the top 10. The top 10 countries in NCIN include six countries of G7 group and three countries of the BRICS; obvious upward trend was detected in the

BRICS through comparison, which reflects that the change trend of cooperative papers of Nano S&T is consistent with economic growth trend.

B. Uneven distribution of international S&T cooperation

Gini coefficient is the indicator judging degree of inequality in economics, whose value range s from 0 to 1. When the distribution is absolutely even, the gini coefficient is zero, when is absolutely uneven, the gini coefficient is 1. This paper uses the indicator of gini coefficient to judge uneven distribution in international S&T cooperative paper.

$$G = 1 - \frac{1}{n}\left[2\sum_{i=1}^{n-1} w_i + 1\right] \quad (1)$$

Take 2012 for example, Algorithm is as follows:

First: rank countries by the numbers of international S&T cooperative papers;

Second：Group based on the above ranking, put every 10 data as a group, and divided into 10 groups as shown in Fig. 3;

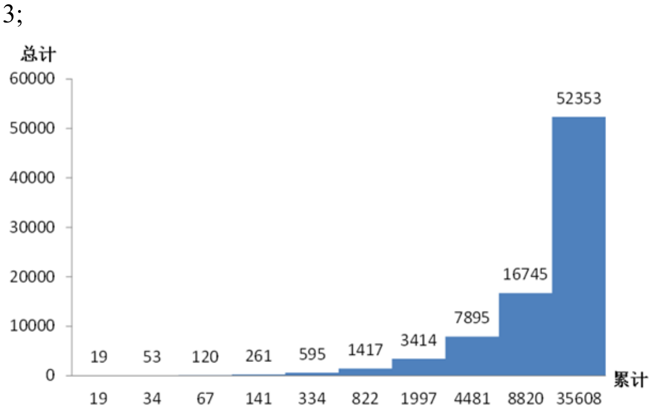

Fig. 3 Packet histogram of the gini coefficient data

Third, first calculate w_1=0.00053， w_2=0.00149， w_3=0.00337，……w9=0.4792，w10=1.4702。according to formula (1)，gini coefficient of 2012 is 0.783. Calculated results of all the years are as shown in Fig. 4:

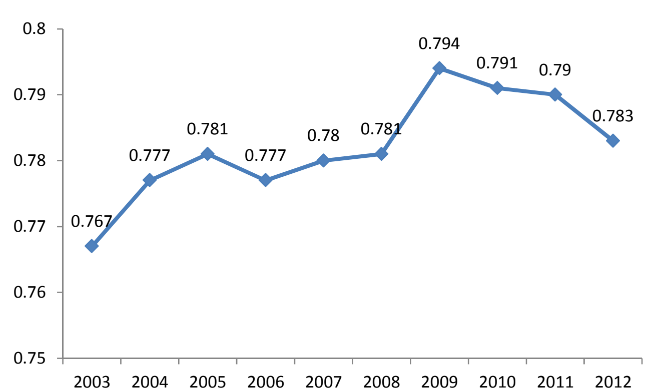

Fig. 4 Calculation results of gini coefficient based on the number of international S&T cooperative thesis

Fig.4 shows the calculation results of gini coefficient, based on the gini coefficient of Nano S&T cooperative paper number calculation, we find that: (1) a rising trend was seen in the gini coefficients from 2003 to 2009, because developed economies such as Japan, Europe and emerging economies such as China, South Korea conducted Nano S&T strategy layout earlier, their Nano S&T development level is higher, in international S&T cooperation, they has played a dominant role. During this period, the gap between strong Nano S&T countries and weak Nano S&T countries gradually widened. After 2009, as more and more countries realize the importance of Nano S&T, the gini coefficient between weak and strong Nano countries decreased gradually, more and more countries promotes the development of Nano S&T; (2) The gini coefficient reflects income gap level. When the gini coefficient is above 0.6, it means the income gap is very big. The value of gini coefficient of international S&T cooperative papers between countries is between 0.767 and 0.794, proving that a large gap exists among countries participating in international S&T cooperation (although the gap has a decrease tendency), thus there is need for core-edge structural analysis and centrality analysis to describe the status and features in the network of the parties involved in international cooperation.

C. Core-edge distribution research in international Nano S&T cooperation network

Based on correlation coefficient algorithm, Borgatti proposed the core- edge structure model, mainly use of the similarity degree of original matrix and ideal matrix to judge the line of core and edge in the network [3]. This paper fits corresponding core/edge model with data network, determines which countries in the international S&T cooperation belong to core countries and which belong to the periphery. Based on UCINET tool, we compute core-edge distribution in international Nano S&T cooperation network every year. The calculation path is as follows: network—core/periphery—categorical, for example, in 2003, the calculation results are as follows, the number of iterations is 50, Starting fitness : 0.000; Final fitness: 0.835. The calculated results show that core countries are USA, Germany, France, Japan, UK, China and the marginal countries are 93 countries including Russia, Italy, South Chesapeake, Canada, and Poland and so on, and finally the density matrix is obtained as follow:

TAB.3 CORE-EDGE COUNTRY DENSITY MATRIX

	Core-Countries	Periphery-Countries
Core-Countries	146.933	9.866
Periphery-Countries	9.866	0.489

Other years' calculation process is omitted, because the number of edge countries is huge, so in the table below only core countries are listed, utilize the change situation of core countries to reflect the change situation of distribution structure of core – edge distribution in international Nano S&T cooperation network.

TAB.4 CORE COUNTRIES IN CORE – EDGE DISTRIBUTION IN NANO COOPERATIVE NETWORK.

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Germany	Germany	Germany	Germany	Germany	Germany	Germany	China	China	China
France	France	France	France	China	China	China	Germany		
Japan	Japan	Japan	China	France	France	France			
UK	UK	China	Japan	UK	UK	UK			
China		UK	UK	Japan	Japan				

As shown in Tab.4, the United States, Germany, France, Japan, Britain, China, the six countries' core positions are relatively stable before 2010, especially the United States and Germany, two Nano S&T powers, while significant growth trend appears in China. In 2011 and 2012, the United States and China became the only two core countries, and in 2004 China even is the edge country in the international cooperation network, but later China entered the core series, and its core position ranking also gradually rose from the 6th in 2003 to the 5th in 2005, the 4th in 2006, the third in 2007, 2008 and 2009, finally in 2010 and 2010 only next to the United States, in the edge -core structure, it's in the core position. Tab.4 shows at the same time, in the Nano international cooperation network, status dominated by America, Japan and Europe cooperation changed into the two pole development of America and China.

D. Centrality analysis of typical countries of international Nano S&T cooperation

Core-edge distribution describes the overall characteristics of Nano S&T cooperation network, centrality analysis is used to measure the importance of nodes in the network structure. Centricity indicators include individual actors' centricity and the whole network's centricity. In social network analysis, degree centrality, betweenness centrality and closeness centrality are relatively common indicators [8].

1) Degree centrality

Degree centralities of point are divided into absolute degree and relative degree. Absolute degree centrality is the number of points connecting to point A, presented as $C_{AD.}$ In the global Nano S&T innovation network, point centrality represents the number of papers that cooperates with A country. If the number is big, the country lies in the centricity, representing larger influence in international cooperation network.

Tab.5 selects degree centrality changes in TOP20 countries in the cooperative paper quantity and Brazil and South Africa who are not in top 20 to analyze countries' degree centricity changes. Analysis results show that the USA, Germany, France, Japan, UK, China and other six countries had obvious advantage in 2003, but in 2012, the gap between these six countries and others are narrowing. Besides, among these countries, the most obvious upward trend was seen in Saudi Arabia, from only 3 cooperative papers in 2003 to 948 in 2012, which is associated with a range of Nano S&T plans in Saudi Arabia, such as the use of nanotechnology for desalination, Nano electronic cooperation development plan, etc. Fast development trend was seen in the BRICS, reflecting that emerging economies played a more and more important role in the international S&T collaboration network.

TAB.5 DEGREE CENTRALITY OF COUNTRIES IN COOPERATIVE NETWORK

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
USA	2912	3479	3990	4921	5514	6172	6907	8042	9092	10129
China	920	1075	1411	1968	2336	2863	3579	4498	5523	6276
Germany	2247	2717	2966	3569	4017	4285	4709	5321	5701	5914
France	1539	1867	2185	2503	2705	3108	3333	3672	3997	4135
UK	1177	1360	1621	1889	2293	2683	2972	3143	3582	3802
Japan	1296	1480	1595	1836	1985	2213	2282	2576	2849	3022
South Korea	582	692	785	1061	1092	1371	1538	1922	2357	2652
……	……	……	……	……	……	……	……	……	……	……
Saudi Arabia	3	9	14	8	22	45	119	255	583	948
Belgium	328	445	419	548	594	680	833	884	1077	1036
Brazil	251	329	341	407	473	513	559	580	654	723
South Africa	30	56	66	48	79	105	129	140	194	255

TAB.6 CENTRALIZATION CHANGES IN NANO COLLABORATIVE NETWORKS

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Centraliaziton	8.04%	7.04%	7.53%	7.74%	6.69%	5.92%	4.59%	4.0%	3.45%	3.49%
Heterogeneity	5.84%	5.64%	5.77%	5.66%	5.59%	5.36%	5.41%	5.33%	5.22%	5.14%
Normalized	4.91%	4.78%	4.92%	4.78%	4.79%	4.53%	4.68%	4.6%	4.53%	4.41%

Centrality degree is an indicator describing a point's centrality in the network; centralization of a graph index depicts the overall centricity of the whole network. The computation formula of central potential is as follows:

$$C = \frac{\sum_{i=1}^{n}(C_{max}-C_i)}{max[\sum_{i=1}^{n}(C_{max}-C_i)]} \quad (2)$$

Obvious decrease trend appeared in center potential of nano collaborative networks from 8.04% in 2003 to 3.49% in 2012, proved that centrality trend of core points in the collaborative networks gradually decrease, that is to say, the most influential country's power(in nano S&T cooperative network is America) decrease gradually.

2) Betweenness centrality

Betweenness centrality was raised by Freeman in1979, which measures the degree of a point lies in the shortest path [17]. In international Nano cooperative network, if a country is midst in several pairs of cooperative countries in the cooperative network, then its betweenness centrality is low, which means the country acts as intermediary in the Nano S&T cooperative network. Based on betweenness centrality, Porter puts forward the concept of structural holes: when two points connect with distance 2 instead of 1, then there is a structure hole between the two.

Restricted by the paper's length, calculation process and results of betweenness centrality are not listed here, conclusions are as follows: (1) French has strong betweenness centricity in the international Nano S&T cooperative network, in 2003-2012, betweenness centricity degree of French remained the lowest or the second lowest position, had big disparity with other countries, in combination with core - edge distribution analysis result, after 2010, though French was not core country, maintained a strong mediation centricity role, embodies French acts as the intermediary and bridge role in the international S&T cooperative network.

In addition, it is important to note that countries one of the BRIC, South Africa, South Africa's cooperative papers quantity ranked near the 50th in 2008-2012, but its ranking of betweenness centrality are respectively, 8, 5, 3, 6, 5, according to the research of Freeman, points whose degree centrality is low and betweenness centrality is high are characterized by self's relationship is of great vitality to network flow. In the study of Nano international S&T collaborative network, the total amount of cooperative paper in South Africa is not huge, but it is very important in the international S&T collaborative network. We extract with VantagePoint software cooperative papers of South Africa in recent five years, find that Top10 countries include emerging economies such as China, India, also developed economies like United States, France, Germany, Britain, Japan, and less developed economies such as Nigeria, Senegal, Malawi, reflecting that South Africa connects less developed economies, emerging economies and developed economies in the international Nano cooperative network.

3) Closeness centrality

Closeness centrality describes degree of a node that is not subject to any other node's control. If a point is close to all other points in the network, we say that point has strong closeness centrality. In the international S&T cooperative network, high closeness centrality means no hole structure in the country's cooperation with other countries, and cooperates close with network core point. Through the analysis results of closeness centrality, we find China is characterized by is higher degree centrality, but low closeness centrality. According to the theory of freeman, this point belongs to embedded center points far away from cluster the in the network, prove that clustering of China and the United States is weak in cooperation network. Another point with high centrality degree and low closeness centrality is Singapore, The extraction results of VantagePoint show that it mainly cooperates with China (in nearly 3 years cooperation with China in Singapore working paper respectively accounted for 47.8%, the number of 44.7% and 44.0%), and prove that China is becoming another pole of Nano science and technology cooperation.(in recent 3 years, papers that cooperated with China in Singapore account for 47.8%, 44.7% and 44.0%),proving China is becoming another pole of Nano S&T cooperation.

E. Bibliometrics analysis of international S&T cooperative papers

Through overall analysis, Gini coefficient, core-edge distribution, central degree analysis, we discuss the core and characteristics of international nano S&T cooperative network above. In this section we select bibliometrics indicators like number of cooperative papers, average cited frequency, highest cited frequency, H index, to evaluate paper quality of top 10 nations, and making clustering analysis of keywords of highly cited papers, find current research hot spot in international Nano S&T cooperation. Average cited frequency and the highest cited frequency are commonly used in bibliometrics indicators [31], "h" put forward by Hirsch is also a common index of literature quality [11]. It can be expressed as a scientific researcher's h indicator is that he has at least h papers which had been cited for h times. For citation analysis has a certain time lag, considering the half cited decrease of Nano journals, we select data in 2009 for analysis.

TAB. 7 INTERNATIONAL S&T COOPERATIVE PAPERS IN 2009

Nation	Number of SCI	Average cited frequency	Highest cited frequency	H indicator
USA	5482	17.57	1869	99
Germany	3299	14.64	593	73
China	3133	15.98	725	75
France	2374	15.26	265	60
UK	2056	15.72	934	66
Japan	1794	12.82	348	52
Spain	1311	13.14	148	48
South Korea	1295	10.89	1869	54
Italy	1174	13.36	209	48
Russia	991	8.69	934	31

As shown in Tab.7, based on the related data in WOS citation report, we find that from the perspective of quality, whether in average cited frequency or in H index, the international Nano cooperative paper of the United States ranks ahead of other countries. Besides, our international Nano S&T cooperative thesis quality also keep high level, the quantity of our international cooperative paper ranks the third in 2009, but the quality of that ranks the second, and we have many highly cited papers. Such results are inconsistent with some research conclusions that Chinese paper output generally are characterized by high quantity but low quality.

To analyze change situation of research hot spots in international nano S&T cooperative thesis, we analyze core keywords of high cited papers from 2003 to 2012. Take 2003 as an example, papers which are cited for 100 times to 389 times are handled for noise reduction by words "stopwords.the, general terms.the". Then we use the software VantagePoint for clustering analysis based on word co-occurrence frequency, generating the factor map of key words and phrases after the noise reductions, which makes visualization for the principal components analysis results of these keywords.

As is shown in Fig.5, each node in the graph shows the clustering of a keyword, the line between two nodes represents the similarity degree of two clustering (value between 0 and 1), different types of lines represent different similarity as the comment box shown. By comparison, we find that hotspot in international Nano S&T cooperative papers changed. In 2003, research hotspots include: ethanol fuel cells (urban traffic particulate matter emissions), biological Nano membrane, nanocrystals, Nano biological virus research, magnetic nanoparticles, ecological, Nano focus X-ray detection, molecular electronics; In 2003, research hotspots include: dropwise condensation, Nano pores, belt, nanoparticles and Nano biomedical, Nano-imprinting lithography technology, etc. which embodies changes in research hotspots in international Nano S&T cooperative fields.

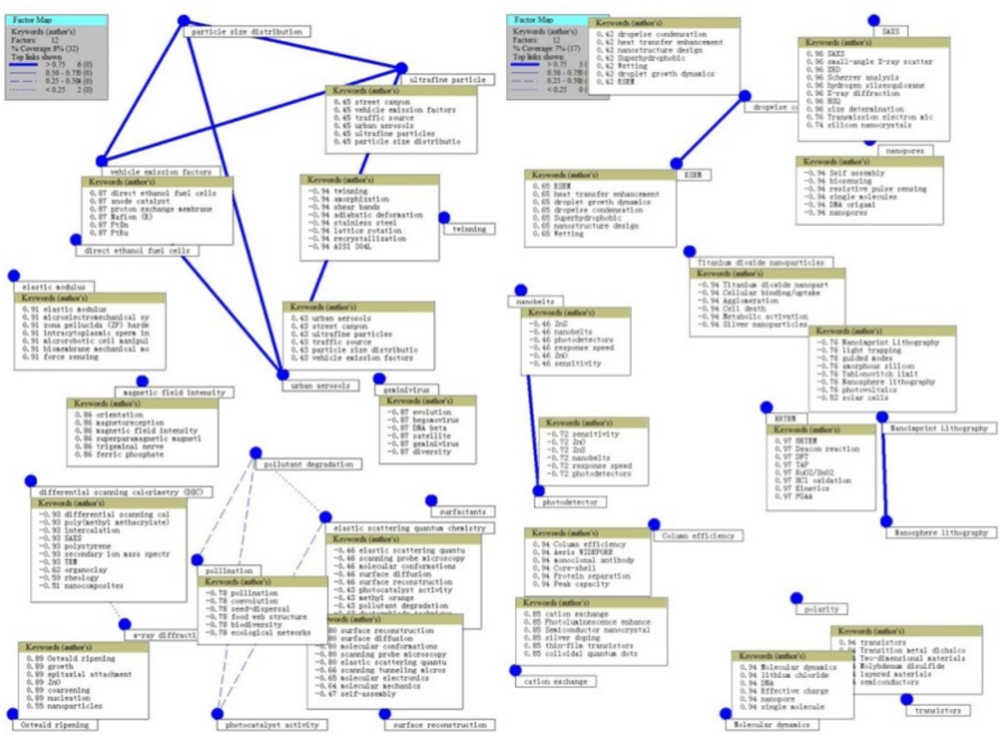

Fig. 5 Changes of research hotspots in international Nano cooperative papers in 2003(left) and 2012(right)

F. Visualization of international Nano S&T cooperative network

We use Gephi software to realize visualization of nano S&T cooperative networks.

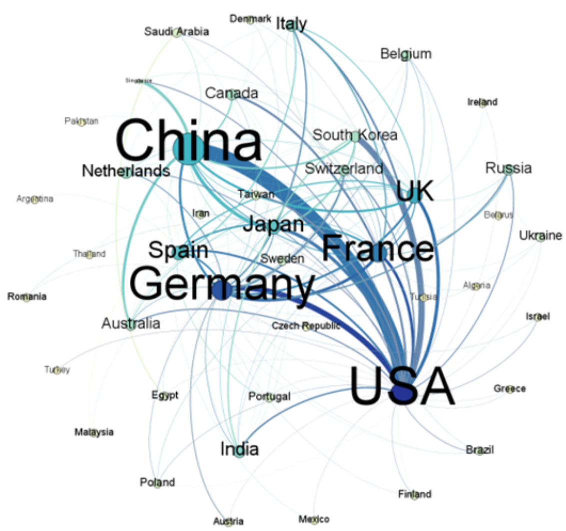

Fig. 6 visualization of international nano S&T cooperative network

Annular distribution is a layout method that places one or a set of nodes in the center and other nodes around concentric circles in sequence [21]. It facilitates users to identify nodes with large centrality degree, also regularly reflect node scale and intensity in the network. We use circular layout algorithm, draw Nano S&T cooperative network mapping as shown in figure 6. In order to make the results more clearly, we set up 50 cooperative papers as threshold, select the number of cooperative times more than 50 and draw international Nano S&T cooperative network. As can be seen in the figure, the United States and China are becoming the two poles in international S&T cooperative network, countries that cooperated closely with China included Pakistan, Singapore, Saudi Arabia and other countries and Taiwan area, etc. France and Germany plays intermediary roles in the international Nano S&T cooperative network.

V. DISCUSSION AND IMPLICATIONS FOR CHINA

(1) The growth trend in total amount of International Nano S&T cooperative papers are close to that of Nano S&T papers, which remains steady in the past 10 years. International cooperative papers account for 22% of Nano papers;

(2) Developed economies like the United States, Japan and Europe have been in dominant position in the international Nano S&T cooperation network. While emerging economies such as China, India is progressing significantly. The top 10 countries in NCIN include six countries of G7 group and three countries of the BRICS, which reflects that the change trend of cooperative papers of Nano S&T is consistent with economic growth trend;

(3) We analyze the gap in NCIN by Gini coefficient and find that the Gini coefficient appeared first widening, then narrowing trend, and reaching its peak in 2009;

(4) The results of core - periphery distribution show that the core position of the six countries (United States, Germany, France, Japan, Britain, and China) is relatively stable before 2010. But with the rapid development of nanotechnology of China, NCIN appears the two- pole (US and China) development status.

(5) The result of point centralization analysis show United States' influence is gradually weakened in the cooperative network. The result of betweenness centrality analysis reflects the bridge and intermediary role of France, South Africa and other countries, The abnormal data of China and Singapore in closeness centrality shows the they are embedded cluster far away from the center points in the network, which validates China is becoming a pole of NCIN from another perspective.

(6) The result of bibliometrics analysis proves that both quantity and quality of international cooperative Nano papers of the United States and China are in leading position, which denies the research conclusion in related research that “Chinese paper output generally has the characteristics of high quantity but low quality". Factor map displays research hotspot changes in nanotechnology cooperation papers.

VI. CONCLUDING REMARKS

Further research prospect includes adding patent data in the follow-up study to analyze features of international Nano S&T collaborative network in the field of technology deepen analysis of interagency cooperation and further grasp the characteristics of international Nano S&T collaborative network.

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