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A bilateral comparison of research performance at an institutional level

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Abstract An extensive body of research indicated that the USA and China were the first two largest producers in the nanoscience and nanotechnology field while China performed better than USA in terms of quantity; it had produced inferior quality publications. Yet, no studies investigated whether the specific institutions are consistent with these conclusions or not. In this study, we identify two institutions National Center for Nanoscience and Technology (NCNST) from China and University of California Los Angeles-California Nanosystems Institute (CNSI) from the USA) and compare their scientific research. Further, we develop and exploit a novel and updated dataset on paper co-authorship to assess their scientific research. Our analysis reveals NCNST has many advantages in regards to author and paper quantities, growth rate and the strength of collaborations but loses dominance with respect to research quality. We do find that the collaboration networks of both NCNST and CNSI have small-world and scale-free properties. Besides, the analysis of knowledge networks shows that they have similar research interests or hotspots. Using statistical models, we test and discover that degree centrality has a significant inverted-U shape effect on scientific output and influence. However, we fail to find any significant effect of structural holes.

Keywords Collaboration network · Knowledge network · Nanoscience · Nanotechnology · Social network analysis (SNA) · Institution

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Introduction

Over the past decade, the world's major economies actively deployed nano-plans in order to seize the promising development opportunities in this field. The USA government launched National Nanotechnology Initiative (NNI) already in 2000 and since then, has invested considerable resources in NNI (Heinze 2004). Analogously, China established the National Steering Committee for Nanoscience and Nanotechnology (NSCNN) in 2001, in order to handle the nanotechnology research direction. In 2006, China's State Council launched the "Program outline for national medium and long term scientific and technical development (2006–2020)" and selected "nanoscience and nanotechnology" as the major field of basic scientific research for science and technology development during this period (Guan and Ma 2007). In recent years, China has become a large producer of nanoscience and nanotechnology papers (Zhou and Leydesdorff 2006; Kostoff et al. 2007, 2008; Leydesdorff and Wagner 2009; Kostoff 2012). The number of these papers grew at an exponential rate and had a short doubling time (Zhou and Leydesdorff 2006; Guan and Ma 2007; Zhou and Bornmann 2014). However, China still lags behind the USA in terms of the number of citations of all nanoscience and nanotechnology papers (Leydesdorff and Wagner 2009; Kostoff 2012). It means that the USA performs better, measured by citations, in producing high quality papers. Some scholars conceived that China ranked second in this field only to the USA (Zhou and Leydesdorff 2006; Guan and Ma 2007; Leydesdorff and Wagner 2009; Guan and Wang 2010; Karpagam et al. 2011). The comparison of China-USA also attracted some other scholars. Tang and Shapira (2011) investigated collaboration in nanotechnology between China and USA. Wang et al. (2012) investigated the racial background of China-USA collaborating scientists. Most of these studies were just at a country level. They indeed provided a general situation of the two countries but were lack of detailed information of specific players in this field. The institutions or centers that represent the national strategic plan and the forefront of the development in nanoscience and nanotechnology field always play the leading and exemplary role in the whole country. They even have a profound impact on the future development or prospect in this field. Recently, by means of "National Nanotechnology Initiative Strategic Plan (2014)", the USA government clearly proposed that they will advance a world-class nanotechnology research and development program. Therefore, specific program or national research centers (institutions) attracted more attention from policy makers and were given priority to their development. Consequently, the general comparison just at country level is far from enough. The analysis of the representative institutions is necessary and very important. It is also consistent with the national policy and strategic positioning in terms of cutting-edge science and emerging technologies such as nanoscience and nanotechnology. It will enable us to grasp the national strategic direction and will promote a deeper and more thorough understanding of the situation in the field of nanoscience and nanotechnology. Studying specific institutions will go into more details and be more targeted as well as full of practical significance. However, there are hardly any comparable institutions. Therefore, it seems that the comparison between institutions has been excluded from mainstream literatures. To sum up, there is a gap to fill. We will have a try to investigate two representative institutions in order to deepen into the country-level comparison by comparing institutions.

Based on the desk research, we first looked through all the institutions in the field of nanoscience and nanotechnology from China and the USA, and then analyzed the comparability from the following aspects: Established Time, Goals/Mission, National Status, Domain Status, Facilities and Research Interests. After these steps, two representative nanotechnology research institutions from China and the USA were finally selected to make the comparison. These are National Center for Nanoscience and Technology (NCNST) and University of California Los Angeles-California Nanosystems Institute (CNSI).

Nowadays, most of high-quality research needs collaborations which have attracted increased attention of scholars for a long time (Cainelli et al. 2015; Bornmann and Leydesdorff 2014; Guan and Liu 2014; Guan et al. 2014; Wang et al. 2013; Lee et al. 2012; Tang and Shapira 2011). Adams (2012, 2013) found that collaborations had a positive effect not only on research performance but also on profits and economic development. The study of complex networks and social networks and its application in diverse fields supply a more clear understanding of the nature of collaboration and innovation (Watts and Strogatz 1998; Ahuja 2000; Newman 2001; Burt 2004; Rodan and Galunic 2004; Rodan 2010; Phelps et al. 2012). To some extent, collaboration networks and knowledge networks pertain to social networks (Abbasi et al. 2012; Fu et al. 2014; Wang et al. 2014). Consequently, social network analysis (SNA) can be adopted in this paper to conduct comparison of two institutions' research performance. We will make an endeavor to investigate their collaboration networks and knowledge networks.

This study makes an attempt to compare the scientific research of two representative nanotechnology research institutions separately from China and the USA. The paper is structured as follows: After the introduction, "Case profile" section provides a profile of two institutions including the explanation of why they have been chosen; Then, the data collection is provided followed by the research methods ("Data and methods" section); The analysis and results ("Analysis and results" section) will include the empirical analysis of the research performance and the comparison of the collaboration networks as well as knowledge networks and will also include the assessment of the relationship between the collaboration networks structures and the research performance; Henceforth, "Conclusions" section will conclude with main findings and the discussions.

Case profile

This section will offer in-depth information about two cases: National Center for Nanoscience and Technology (NCNST) from China and University of California Los Angeles-California Nanosystems Institute (CNSI) from the USA. They are all parts of long-term strategy at the national level and could be considered as representatives of each country's institutions in nanoscience and nanotechnology field. Furthermore, we analyzed the comparability from the following aspects: Established Time, Goals/Mission, National Status, Domain Status, Facilities and Research Interests. Finally, we concluded that they were considered to be sufficiently comparable.

NCNST

National Center for Nanoscience and Technology (NCNST) was co-built in December 2003 by the Chinese Academy of Sciences, Tsinghua University, and Peking University. NCNST is dedicated to the development of basic and applied research of nanoscience and nanotechnology, aiming at becoming a world-class public technology platform and research base that are open to both domestic and international users. In other words, it wants to be China's window for international collaboration and a research base for fostering talents. Zhao (2013) claimed that NCNST was performing the following functions: "promoting scientific research in the major areas of nanoscience and related technology; supporting material characterization for both academia and industry; building partnerships among government, academia, and industry; speeding up nanotechnology transfer; offering education and training in nanotechnology to students and young researchers; informing the public about nanotechnology; organizing international/national conferences; and establishing standards and accreditation for nanomaterial applications."(p. 2381). It could be said that NCNST "serves as a bridge between academia and industry, and plays a vital role in the promotion and translation of nanotechnology" (Zhao 2013, p. 2381). Since the inception, NCNST has invested heavily in order to purchase equipment which is normally too expensive for a single institute or university to afford. Meanwhile, NCNST takes advantage of existing equipment from Chinese Academy of Sciences, Peking University, and Tsinghua University to establish network-type laboratories and also cooperates with Peking University Health Science Center in building 19 coordination laboratories (NCNST 2014a).

CNSI

University of California Los Angeles-California Nanosystems Institute (CNSI) is an integrated research facility that was erected in December 2000. For the sake of enhancing a leading-edge position in the field of science, technology and economy as well as catering to the arrival of a high tide of technological revolution, the State of California sponsored CNSI as a nanotechnology research and transformation platform (UCOP 2014). CNSI was initiated by the University of California at Santa Barbara (UCSB) and the University of California at Los Angeles (UCLA), both of which supplied strong technology and talents supports. CNSI is a multidisciplinary program that has a highly talented group of researchers to push forward the advancement of nanotechnology research which could facilitate California and the nation to develop the manufacturing, biomedical and information technologies. Energy, Environment, Health-Medicine, and Information Technology are the four targeted areas of nanosystems-related research at the CNSI. Its mission is "to encourage university collaboration with industry and to enable the rapid commercialization of discoveries in nanoscience and nanotechnology" and the vision is to "establish a coherent and distinctive organization that serves California and the nation, and is embedded on the UCSB and UCLA campuses" (CNSI 2014a). CNSI builds upon "the existing collaborative strengths of its on-campus participants, and seeks new alliances with industry, universities, and national laboratories" and also builds on "a visionary investment in future education, research and technological resources given by the State of California" (CNSI 2014b). The CNSI at UCLA has eight core facilities serving industry and academic collaborations. CNSI covers 188,000 square feet and has wet and dry laboratories, a 260-seat theater and fully outfitted conference rooms. Besides, it also has three floors of core facilities and equipments such as atomic force microscopes, electron microscopes, specialized optical microscopes, X-ray diffraction microscopes, clean rooms of class 100 and 1000 for projects and high throughput robotics used for molecular screening (CNSI 2014a).

Comparability of NCNST with CNSI

As mentioned above, the first step of the case selection process is looking through all the institutions in the field of nanoscience and nanotechnology from China and the USA, and then analyzed the comparability from the following aspects: Established Time, Goals/Mission, National Strategic Status, Domain Status, Facilities and Research Interests (Table 1). After carefully comparing of NCNST with CNSI (Table 1), we found that both of them had been established about a decade's time. This is a very important precondition for the comparison. Besides, these two institutes are all initiated by the state or government sponsored program in the same context or background of the development of nanotechnology all over the world. For example, the council of NCNST is composed of representatives from many National Ministries and local governments. It is a national integrated center of China in the field of nanotechnology (NCNST 2014a). NCNST is also "a part of the long-term strategy at the national level for the development of multidisciplinary science" (Zhao 2013, p. 2381). Correspondingly, CNSI is a "multidisciplinary research partnership between UCLA and UCSB established by the state legislature and California industry in 2000 as one of the first California Institutes for Science and Innovation" (CNSI 2014c). CNSI is also one of the ten outstanding research centers that were established by the National Nanotechnology Initiative (NNI). Consequently, they are all parts of long-term strategy at the national level which is why they gained many supports from the governments and their co-founders. This enables both of them to have advanced laboratories and equipment. The co-founders of NCNST and CNSI are prolific actors or universities (CAS, Tsinghua University, and University of California) in the field of nanoscience and nanotechnology when considering patents they hold. Finally, they have many common research interests such as Single Molecules Sciences, Biological Effects of Nanomaterials and Nano-Medicine. These interests enable them to sign a Memoranda of Understanding (MOU) in 2010 (NCNST 2014b). Based on this, they finally reached a cooperation intention.

Because of the highly similar established time, goals/mission, national strategic status, research interests, background and contexts of the NCNST and CNSI, they are considered to be sufficiently comparable.

Data and methods

Data collection

This study used the data derived mainly from the Web of Science Core Collection database which includes Science Citation Index Expanded, Social Sciences Citation Index, Arts and Humanities Citation Index, Conference Proceedings Citation Index-Science, and Conference Proceedings Citation Index—Social Science and Humanities. In order to get an accurate result, we previously retrieved some articles and finally identified the retrieval strategy (Table 2).

In order to ensure that at least one author from NCNST was involved, we took #1 as the article retrieval strategy for NCNST and obtained 1972 documents. We set the time span from 2004 to 2013 because NCNST was established in December 2003. In the same vein, we set the time span from 2001 to 2013 for CNSI and obtained 1687 documents followed #2. We mainly referred to address by reason that we just found several articles when using

Table 1 The comparison of NCNST with CNSI

Content	NCNST	CNSI
Established time	December 2003	December 2000
Goals/mission	Goals: "To promote scientific research in the major areas of nanoscience and related technology; to support material characterization for both academia and industry; to build partnerships among government, academia, and industry; to speed up nanotechnology transfer; to offer education and training in nanotechnology to students and young researchers; to inform the public about nanotechnology and etc."(Zhao 2013, p. 2381) Mission: "To build a public technological platform and research base for nanoscience, which is featured with state-of-the-art equipments and is open to both domestic and international users"(NCNST 2014a)	Goals: "To provide a world-class intellectual and physical environment; to generate the ideas, discoveries and the talent that will continue to fuel innovation in nanosystems; to foster interdisciplinary collaboration; to support and mentor the next generation of scientists and engineers; to provide crucial instrumentation and facilities necessary to propel the next generation of nanosystems discoveries"(CNSI 2014c) Mission: "To create the collaborative, closely-integrated and strongly interactive environment that will foster innovation in nanosystems research and education" (CNSI 2014c)
National status	NCNST is co-built by Chinese Academy of Sciences (CAS) and Ministry of Education. Center of Nanoscience and Nanotechnology of CAS, Peking University and Tsinghua University are its initiators and co-founders. The council of NCNST is composed of representatives from National Development and Reform Commission, Ministry of Science and Technology, Ministry of education, Ministry of Finance, Ministry of Health, Beijing Government, and Natural Science Foundation of China. It is a national integrated center of China in the field of nanotechnology (NCNST 2014a). It is "a part of the long-term strategy at the national level for the development of multidisciplinary science" (Zhao 2013, p. 2381)	CNSI is a "multidisciplinary research partnership between UCLA and UCSB established by the state legislature and California industry in 2000 as one of the first California Institutes for Science and Innovation"(CNSI 2014c) CNSI is one of the ten outstanding research centers/networks that were established by the National Nanotechnology Initiative (NNI). It plays an important role in achieving the key objectives (basic research, major challenges and the training of future scientists and engineers) of NNI (CAS 2003)
Domain status	As co-founders of NCNST, Chinese Academy of Sciences (CAS) and Tsinghua University respectively ranked NO. 11 and 30 regarding the amount of nanotechnology patents around the world during the period of 1991–2008. Besides, Tsinghua University was the second most active universities in nanotechnology patents around the world during this time (Guan and Wang 2010)	As the initiator of CNSI, University of California ranked NO. 8 regarding the amount of nanotechnology patents around the world during the period of 1991–2008. Besides, University of California was the most active universities in nanotechnology patents around the world during this time (Guan and Wang 2010)

Table 1 continued

Content	NCNST	CNSI
Facilities	NCNST currently has 6 research offices, 2 laboratories and 19 coordination laboratories. These branches mainly are laboratory for nanodevice, nanomaterials, biological effects of nanomaterials and nanosafety, nanocharacterization, nanostandardization, nanomanufacture and applications, as well as testing laboratory for nanostructures, coordination laboratories, nanofabrication laboratory and some databases for nanoscience (NCNST 2014a)	The CNSI at UCLA has eleven core facilities serving industry and academic collaborations. It covers 188,000 square feet and has wet and dry laboratories, a 260-seat theater and fully outfitted conference rooms. Besides, it also has three floors of core facilities and equipments such as atomic force microscopes, electron microscopes, specialized optical microscopes, X-ray diffraction microscopes, clean rooms of class 100 and 1000 for projects and high throughput robotics used for molecular screening (CNSI 2014a, d)
Research interests	The main research directions of NCNST are basic and applied researches in nanoscience. They mainly consist of "system integration technology of nanostructure, standardization of nanotechnology and manufacture of nanoscale materials, research on biology effect and safety of nanostructure, related fundamental research on nanofabrication, significant manufacture of nanostructure and key analysis technology," molecules sciences, biological effects of nanomaterials, nano-medicine and etc. (NCNST 2014a)	Energy, Environment, Health-Medicine, and Information Technology are four targeted research areas of CNSI. It specifically emphasizes "renewable energy, alternative fuels, hydrogen storage, water purification, nanosafety and nanotoxicology, three-dimensional batteries, early-stage medical diagnostics, targeted drug delivery, and molecular switches" (CNSI 2014d). Besides, it also interests in molecules sciences, biological effects of nanomaterials, nano-medicine and etc. (NCNST 2014b)

Table 2 Article retrieval strategy

Set	Retrieval strategy
#1	ORGANIZATION-ENHANCED = (NATIONAL CENTER FOR NANOSCIENCE and TECHNOLOGY—CHINA) or (NATL CTR NANOSCI TECH NCNST) or (NCNST) or (NATIONAL CENTER FOR NANOSCIENCE AND TECHNOLOGY (NCNST)) or (NATL CTR NANOSCI) Time span = 2004–2013
#2	ORGANIZATION-ENHANCED = (UNIVERSITY OF CALIFORNIA LOS ANGELES CALIFORNIA NANOSYSTEMS INSTITUTE) or (CALIFORNIA NANOSYSTEMS INSTITUTE) or (CNSI) or ADRESS = (CALIF NANOSYST INST) Time span = 2001–2013

the name of the institute. In addition, referring to the current practices in the field of nanoscience and nanotechnology in scientometric research (Kostoff et al. 2007; Kostoff 2012; Guan and Wang 2010), we limited those data just to "Article" rather than "Review", "Proceeding", "Editorial", "Letter" and other types "in order to focus on the original research component in the database" (Wang and Guan 2010, p. 342). After refining, we finally got 1789 articles for NCNST and 1252 articles for CNSI.

Each document includes the information of Abstract (AB), Authors (AU), New ISI Keywords (ID), Cited Reference Count (NR), Publication Date (PD), Publication Year (PY), Times Cited (TC), Title (TI) and etc. There are four reasons that we used paper data rather than patent data. The first reason is that the patent data of NCNST is very limited. Less than ten patents have been included by United States Patent and Trademark Office (USPTO) database since its inception. Meanwhile, China's State Intellectual Property Office (CSIPO) includes no more than 300 patent data of NCNST. Such a small number does not facilitate international comparison. Second, papers are inextricably linked to research activities and then the paper would be an important indicator for measuring the performance of scientific activity. Third, papers are always peer-reviewed and the rule of this determines the paper's publication and can guarantee its quality. The fourth factor is that highly standardized paper data could facilitate our research and study.

In the part of analysis of research performance and collaboration networks (for NCNST), we explain variables in subsequent time frame with variables in the previous time frame. Regarding this, we set 5-year as a time window for the data which is divided into two time frames (2004–2008 and 2009–2013). It could be considered as a longitudinal analysis over a span of 10 years. In this way, we got 374 articles and 894 authors in the period of 2004–2008; 1416 articles and 2757 authors in the period of 2009–2013. 894 authors in both time periods will be used as the analysis sample of the assessment of the relationship between collaboration networks structures and the research performance.

Methods

Citations and research performance

The aim of publishing papers is not simply to receive peer recognition, but also to supply inspirations or ideas for latecomers and stimulate them to further improvement and thus promote scientific progress. To some extent, citations could reflect the quality and influence of the paper (Guan and Gao 2008; Tang and Shapira 2011; Bajwa et al. 2013; Guan and Liu 2014). Total citations and average citation times of paper are widely used for the assessment of the influence of the author, institution and country. The more innovative and original the paper, the more valuable it is. Consequently, it would be frequently cited (Guan and Gao 2008; Guan and Liu 2014). This is the logic that Thomson Reuters predicts Nobel Prize winners. In this study, we will compare the article and author citations of the two institutions.

Collaboration networks

As previously noted, collaboration networks pertain to social networks. The related research has been attracted increased attention of many scholars for many years. In this study, we also adopted such method [social network analysis (SNA)]. In collaboration networks, author is regarded as vertex or node and the cooperation of two authors (co-authors) represents the line or tie between two vertices. Such vertices and lines construct collaboration networks, which have many structure properties. According to the current literature in comparing social networks (Wang and Guan 2011; Balconi et al. 2004), we focused on the following network measures.

Node degree (k_i) is reflected by the number of links that incident upon a node. Based on this definition we can calculate *average degree* using the following formula.

$$\text{Average degree Ad} = \sum_{i}^{n} k_i/N \tag{1}$$

The largest connected component is another conception in SNA. Networks are generally composed by the connected sub-networks. If any other vertex or tie of the original networks is added to the sub-networks, the connectivity will be destroyed. Among these sub-networks, the one that has the largest number of vertices is the largest connected component. The ratio of its vertices to the vertices of the entire networks is an important parameter to measure the stability of the networks (Albert et al. 2000). As another property of networks, *density* (D) is defined as a ratio of the number of lines to the number of possible lines [Formula (2)], where e_i is the count of edges among vertices in the neighborhood of vertex i and N is the number of vertices. It refers to how many potential lines in a network actually exist.

$$\text{Density}\, D = 2\sum e_i/N(N-1) \tag{2}$$

The *average path length* (*APL*) is another important measure of networks. It refers to the average length of the shortest path between pairs of nodes in a network and can be calculated by formula (3) (Uzzi and Spiro 2005). Where, d_{ij} refers to the shortest distance between the nodes of i and j; the distance indicates that the minimum number of edges from one node to another. The longest distance in the networks is defined as *diameter*. In other words, it is the longest length of shortest path between pairs of nodes in a network. “If APL is low, the actors in the network are close together and flows across the network are easy.” (Cainelli et al. 2015, p. 682). Average path length (APL) and diameter are the measures of the transmission performance and efficiency of networks.

$$\text{Average path length APL} = \frac{2\sum_{i\geq j} d_{ij}}{N(N+1)} \tag{3}$$

Clustering coefficient is a measure of the aggregation degree of networks. *Clustering coefficient of vertex* (CC_i) is measured by formula (4). Where, k_i denotes the degree of vertex i and e_i is the number of edges or lines among vertices in the neighborhood of vertex *i*. *Clustering coefficient of network* is the arithmetic mean of all cluster coefficients of vertices (5). It is obvious that $0 \leq \mathrm{CC} \leq 1$. If $\mathrm{CC} = 0$, all the nodes are isolated; $\mathrm{CC} = 1$, the networks are fully coupled, in other words, any two nodes are directly connected.

$$\mathrm{CC}_i = \frac{2e_i}{k_i(k_i - 1)} \tag{4}$$

$$\mathrm{CC} = \frac{\sum_{i=1}^{n} \mathrm{CC}_i}{N} \tag{5}$$

Knowledge networks

As mentioned previously, knowledge networks also pertain to social networks and are widely known to enhance creativity and innovation (Wang et al. 2014). A substantial research has proved that social networks are influential in knowledge creation, transfer and adoption (Phelps et al. 2012). That is the reason why they are included in this study. Knowledge network is “a set of nodes—which can represent knowledge elements, distributed repositories of knowledge, and/or agents that search for, transmit, and create knowledge—that are interconnected by relationships that enable and constrain the acquisition, transfer, and creation of knowledge" (Phelps et al. 2012, p. 1156). Compared with collaboration networks, knowledge networks have unique features. The nodes are not the authors but the knowledge elements of science or technology (Carnabuci and Bruggeman 2009; Yayavaram and Ahuja 2008). In other words, the knowledge element is the node; and the line is represented by the combination of two knowledge elements in previous invention (Carnabuci and Bruggeman 2009). The knowledge element is a "socially defined category, containing a set of tentative conclusions that the research community of a scientific or technological field holds about facts, theories, methods, and procedures surrounding a subject matter" (Wang et al. 2014, p. 485). The knowledge element or metaknowledge is an important concept. Metaknowledge is "knowledge about knowledge" that results from "the critical scrutiny of what is known, how, and by whom" (James and Jacob 2011, p. 721). The knowledge element (metaknowledge) is not inherent as atomic, but associated with the previous application of inventions (Fleming 2001), and henceforth, gradually blooms into knowledge networks that record their combinatorial histories over time (Carnabuci and Bruggeman 2009; Wang et al. 2014). Metaknowledge analysis can be a content analysis, frequency evaluation, co-occurrence of words, phrases and concepts (James and Jacob 2011).

In this study, we regard keywords as knowledge elements or metaknowledge. Based on the data we collected, "ID (New ISI Keywords)" will be used in the analysis of knowledge networks. Thereafter, we will make a comparison of NCNST with CNSI and endeavor to investigate their research hotspots. Of course, it mainly involves explicit knowledge rather than tacit knowledge.

Variables

Degree centrality (Sabidussi 1966) is conceived as the number of links that a node has. In fact, it is node degree ($\mathrm{DC}_i = k_i$) which can reflect the centrality of a vertex in a simple and intuitive way. In this study, the node degree represents the number of authors that are directly connected with the focal author. If an author has a high node degree, he/she is close to the center of the collaboration networks. Consequently, it could be assumed that the higher of the degree centrality an author possesses the more co-authors he/she has, and then has greater influence.

Structural holes represent the non-redundant relationship between two nodes in networks (Burt 2004). When the distance between two nodes is two instead of one, there will be a structural hole (Abbasi et al. 2011) or it could be seen as a triadic closure—"whether or not a focal individual's direct contacts have ties to each other; when two of the node's contacts do not share a tie, a structural hole exists between them; when all three maintain ties with one another, the triad is closed" (Phelps et al. 2012, p. 1123). In social networks, an individual would be directly connected with others but indirectly connected with some others and thus the structure of the whole networks seems to have a "hole". Structural holes enable someone to play a role of intermediary or broker. Such brokers are easy to have good ideas or performance with respect to other network members because they act as a bridge between otherwise unconnected individuals or sub-groups (Burt 1992, 2004; Fleming et al. 2007; Cainelli et al. 2015). This conclusion is consistent with common intuition. Brokers, who connect the other two disconnected individuals, can control the exchange or information transmission between them.

Burt (2004) proposed a method to calculate dyadic constraint as a measure of structural holes (7). In this study, when the authors connecting with the focal author i are also tightly connected with each other, there must be no or few structural holes in the collaboration networks with a high dyadic constraint, and vice versa. As shown in Eq. (6), P_{ij} represents the proportion of the value of author i's relation(s) with j compared to the total value of all relations of author i. where a_{ij} is the value of the line from author i to j. P_{ik} and P_{kj} have similar meanings.

$$P_{ij} = \frac{a_{ij} + a_{ji}}{\sum_{k,k\neq i,k\neq j}(a_{ik} + a_{ki})} \tag{6}$$

$$C_{ij} = \left(P_{ij} + \sum_{k,k\neq i,k\neq j} P_{ik}P_{kj}\right)^2 \tag{7}$$

We can reason that three factors determine the value of this dyadic constraint C_{ij}. The first is the number connections of author i. The lower is the P_{ij} and then C_{ij}, the higher it is. The second one is the number of third-party authors (denoted by k) that connect to both i and j. The last factor is the total number of all relations of the third-party author k has.

Then we can easily arrive at a measure of aggregate constraint C_i with a simple algorithm (8).

$$C_i = \sum_j C_{ij} \tag{8}$$

For the reason of C_i is sometimes bigger than 1 (Lee 2010) and it will have no effect on the result, we will subtract C_i from 2 (Wang et al. 2014). As such, S_i will reflect the extent to which authors tied to a focal author i are disconnected.

$$S_i = 2 - C_i \tag{9}$$

Analysis and results

Comparison of research performance and collaboration

As previously noted, NCNST was established 3 years later than CNSI. During these 3 years (from 2001 to 2003), the development of CNSI was relatively slow (Table 3). They published 22 articles in total. The performance of the third year was relatively better; 16 articles were cited 3043 times. For the purpose of comparison, we set the time from 2004 to 2013, and thus they would be in the same period.

As can be seen from Tables 4 and 5, both NCNST and CNSI had a significant growth with respect to the number of authors and articles from 2004 to 2013. NCNST published 23

Table 3 CNSI research performance during 2001–2003

Year	Works	Authors	Authors per work	Citations
2001	1	7	7	252
2002	5	34	6.8	662
2003	16	94	5.875	3043

Table 4 NCNST research performance during 2004–2013

Year	Works	Authors	A/W	TC	AC	RGR	Dt	Puc (%)
2004	23	110	4.78	1576	69	–	–	1
2005	56	342	6.11	6928	124	1.23	0.56	3
2006	63	420	6.67	5269	84	0.59	1.18	4
2007	102	666	6.53	3235	32	0.54	1.28	6
2008	130	881	6.78	4011	31	0.43	1.62	7
2009	180	1117	6.21	4093	23	0.39	1.76	10
2010	216	1362	6.31	5870	27	0.33	2.11	12
2011	293	1984	6.77	6081	21	0.32	2.15	16
2012	308	2109	6.85	4512	15	0.25	2.72	17
2013	418	2892	6.92	1646	4	0.27	2.60	23

A/W, authors per article; TC, total number of citations; AC, average citations per work; Puc %, percentage of articles

Table 5 CNSI research performance during 2004–2013

Year	Works	Authors	A/W	TC	AC	RGR	Dt	Puc(%)
2004	32	166	5.19	5086	159	–	–	3
2005	49	248	5.06	3481	71	0.93	0.75	4
2006	80	415	5.19	5312	66	0.69	1.01	7
2007	72	363	5.04	7325	102	0.37	1.88	6
2008	96	473	4.93	10,039	105	0.35	2.01	8
2009	126	696	5.52	6425	51	0.32	2.14	10
2010	173	1141	6.60	7743	45	0.32	2.15	14
2011	197	1276	6.48	4351	22	0.27	2.54	16
2012	185	1304	7.05	3473	19	0.20	3.43	15
2013	220	1645	7.48	1793	8	0.20	3.52	18

A/W, authors per article; TC, total number of citations; AC, average citations per work; Puc %, percentage of articles

articles in 2004 and jumped to 418 in 2013; the number of authors was 110 in 2004 and soared to 2892 in 2013 (about 26 times of the year 2004). CNSI published 32 articles in 2004 and arrived at 220 in 2013; the number of authors obtained ten times growth, from 166 in 2004 to 1645 in 2013. In addition, it is not difficult to find that the number of articles published by NCNST during the last 5 years (2009–2013) accounted for 79 % of its total number of articles; this proportion for CNSI is 73 %. Consequently, both institutions had an excellent performance in the last 5 years compared to the first 5 years. It also indicates that the scientific output of both institutions developed rapidly in the last 5 years. Of course, NCNST performed better than CNSI taking the number of articles and authors into consideration.

Besides, relative growth rate (RGR) and doubling time (D_t) are always used to measure the growth trend in publications (Mahapatra 1985; Karpagam et al. 2011; Bajwa et al. 2013; Guan and Liu 2014). In this study, we will compare these two parameters. RGR can be expressed as

$$\mathrm{RGR} = \frac{\ln N_2 - \ln N_1}{t_2 - t_1} \tag{10}$$

where, N_1 and N_2 respectively represent the number of cumulative articles in the year of t_1 and t_2. In this study, $t_2 - t_1$ is the constant value 1 and therefore $\mathrm{RGR} = \ln N_2 - \ln N_1$. D_t is calculated as

$$D_\mathrm{t} = (t_2 - t_1)\ln 2/(\ln N_2 - \ln N_1) \tag{11}$$

Or

$$D_\mathrm{t} = \ln 2/\mathrm{RGR} \tag{12}$$

From the above equations, we can see that RGR is “a measure to study the increase in number of articles of time” (Karpagam et al. 2011, p. 506). It reflects the relative growth rate of the amount of articles in each period ($t_2 - t_1$). The higher value of RGR translates into faster growth. For example, when the number of articles doubles its size ($N_2 = 2N_1$) over a year ($t_2 - t_1 = 1$), we can get $\mathrm{RGR} = \ln N_2 - \ln N_1 = \ln 2 = 0.69$. If the number is treble ($N_2 = 3N_1$), the value of RGR will be 1.10 (ln3). For the sake of having a direct-viewing of the growth trend, we can also refer to another directly related parameter D_t which is the time that took for the articles to double the size or number of the existing amount. Tables 4 and 5 list the results of RGR and D_t for the two institutions during 2004–2013. The RGR of both NCNST and CNSI all declined from the very beginning and the corresponding D_t gradually increased. Although RGR has been declining, the value changed only a little or even not changed in some years. Constant RGR indicates that the number of articles undergoes exponential growth (Karpagam et al. 2011; Bajwa et al. 2013; Guan and Liu 2014). We can also find that the RGR of NCNST is generally higher than CNSI in most years and doubling time (D_t) is relatively shorter.

The dotted lines in Fig. 1 indicate the number of published articles of the two institutions during 2004–2013. We can clearly see that NCNST began to publish more articles every year than CNSI since 2007 and the gap was widening year by year. This further indicates that the research performance of NCNST has an obvious advantage compared to the CNSI regarding the number of articles. When looking back to the trend during 2012–2013, the development momentum of NCNST is also better than CNSI.

Solid lines in Fig. 1 show the number of authors per article of the two institutions during 2004–2013. The number of authors per article remained 5–7 and was relatively stable in general. However, NCNST had a significantly larger number than CNSI from 2005 to 2009 and henceforth they gradually arrived at the convergence. We can also calculate that the number of authors per article of NCNST is 6.64 in the period of 2004–2013, whereas the value of CNSI is 6.28. It means that the cooperation scale of authors at NCNST is slightly larger than CNSI. Throughout this decade, such numbers of both institutes steadily rose from about 5 in 2004 to about 7 in 2013. It was significantly higher than other disciplines, such as 3.75 in biomedicine, 3.35 in astrophysics, 2.53 in IT and 2.26 in condensed state physics (Newman 2001).

Solid lines in Fig. 2 show the citations of two institutes. It can be seen that NCNST had fewer citations than CNSI in most years. However, NCNST once overtook CNSI in 2005, 2011 and 2012. According to the previous analysis, NCNST has significantly more articles in recent years than CNSI, and the gap is widening. To this extent, the research output has advantages. It is not difficult to understand that the total number of citations of NCNST is higher than CNSI or even overtook it in some years, especially in recent years. On the other

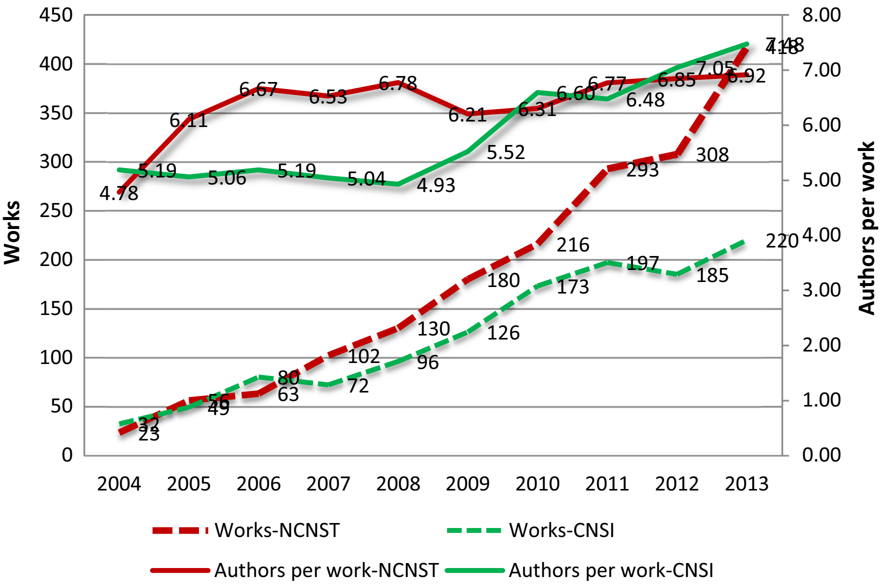

Fig. 1 Articles and authors per article of NCNST and CNSI during 2004–2013

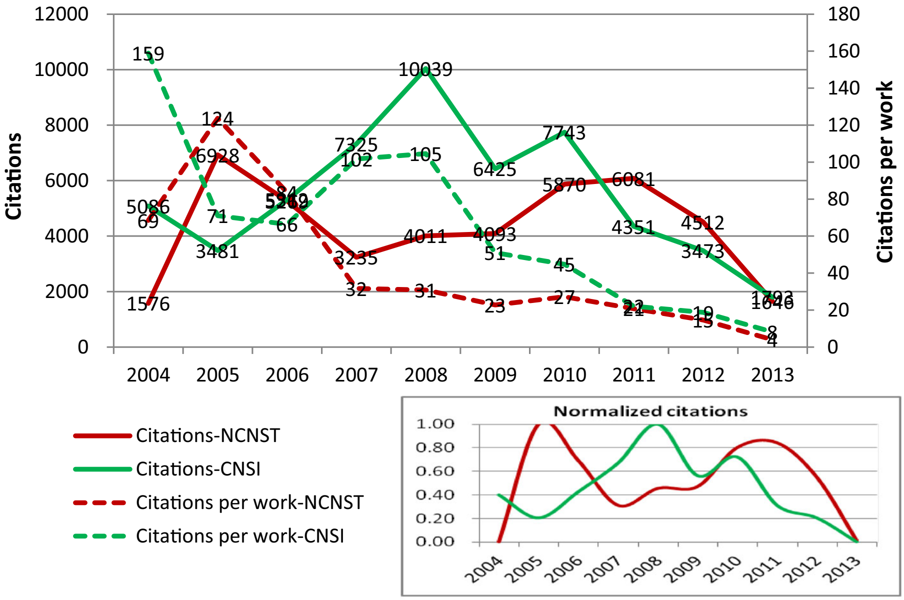

Fig. 2 Citations and citations per article of NCNST and CNSI during 2004–2013

hand, the dotted lines in Fig. 2 demonstrate that the citations per article of NCNST were less than CNSI in most years during this period. In some years, such as 2007, 2008, the gap was very large. It indicates that NCNST published more articles than CNSI, but had less academic and social influence. In other words, the quality of articles is slightly inferior. In recent years, the gap is gradually narrowing (Fig. 2). Figure 2 also shows that both citations and citations per article were declining in the past 5 years, which is mainly because of the time lag. A paper needs a longer time to have an impact or influence. The number of citations will gradually increase over a period of time (e.g. 3–5 years), therefore this trend does not mean that the academic or social influence of the two institutions was declining year by year.

In addition, some measures of collaboration are always and widely used in bibliometrics. We employed four parameters: the collaboration index (CI), degree of collaboration (DC), collaborative coefficient (CC) and modified collaborative coefficient (MCC). They are defined as (Ajiferuke et al. 1988; Savanur and Srikanth 2010; Karpagam et al. 2011; Bajwa et al. 2013)

$$\mathrm{CI} = \frac{\sum_{j=1}^{k} j f_j}{N} \tag{13}$$

$$\mathrm{DC} = 1 - \frac{f_1}{N} \tag{14}$$

$$\mathrm{CC} = 1 - \frac{\sum_{j=1}^{k} \frac{1}{j} f_j}{N} \tag{15}$$

$$\mathrm{MCC} = \frac{A}{A-1}\left\{1 - \frac{\sum_{j=1}^{k} \frac{1}{j} f_j}{N}\right\} \tag{16}$$

where N is the total number of articles in a certain year; f_j refers to the number of articles that have j authors in a certain year; k represents the greatest number of authors an article has in a certain year and A indicates the total number of authors. CI measures average authors per article has (Eq. 13); DC evaluates the proportion of articles having at least two authors among all articles (Eq. 14); CC takes the difference between single authors and multiple authors into account and treat different levels of multiple authorships differently (Eq. 15); MCC modifies the meaning of value 1 when no single authors (Eq. 16, where $A \neq 1$ because collaboration requires at least two authors) and CC is less than MCC for the reason of $1 - 1/A$. It approaches MCC just when $A \to \infty$. The values of CI, DC, CC and MCC of NCNST and CNSI each year during 2004–2013 are calculated and displayed in Table 6. In fact, CI is the number of authors per article. It was already analyzed above. As 1 represents maximum collaboration, DC is rather high for both NCNST and CNSI. CC and MCC are listed in the last two columns. They are all relatively high when comparing them with some other countries in the nanoscience and nanotechnology field (Karpagam et al. 2011; Bajwa et al. 2013). We can also clearly see that all of these annual parameters of NCNST are mostly greater than CNSI. When investigating the whole period (2004–2013), we found that NCNST had one article written by a single author. This means its DC is 99.9 %; meanwhile, the number of articles that were written by no less than 4 authors accounted for 90.1 %; no less than 10 authors articles accounted for 13.6 %. We also found that a maximum of 42 authors cooperated to write one paper together in 2013. It could be regarded as a typical large-scale teamwork. The same analysis applied on CNSI, we found that it had 6 articles written by a single author, based on this, we concluded that its DC was 99.5 %; the number of articles that were written by no less than 4 authors accounted for 80.3 %; no less than 10 authors articles accounted for 13.7 %. A maximum of 35 authors cooperated to write one paper together in 2010. All of these reflect a common

Table 6 Authorship collaborations index of NCNST and CNSI

Year	NCNST				CNSI			
	CI	DC	CC	MCC	CI	DC	CC	MCC
2004	4.7826	1.0000	0.7646	0.7716	5.1875	1.0000	0.7559	0.7604
2005	6.1071	1.0000	0.7822	0.7845	5.0612	0.9592	0.7413	0.7443
2006	6.6667	1.0000	0.8098	0.8117	5.1875	0.9875	0.7471	0.7489
2007	6.5294	1.0000	0.8035	0.8047	5.0417	1.0000	0.7425	0.7446
2008	6.7769	1.0000	0.8160	0.8170	4.9271	1.0000	0.7486	0.7502
2009	6.2056	1.0000	0.8104	0.8111	5.5238	0.9921	0.7701	0.7712
2010	6.3056	0.9954	0.8084	0.8090	6.5954	0.9942	0.7951	0.7958
2011	6.7713	1.0000	0.8274	0.8278	6.4772	0.9949	0.8028	0.8035
2012	6.8474	1.0000	0.8302	0.8306	7.0486	1.0000	0.8045	0.8051
2013	6.9187	1.0000	0.8266	0.8269	7.4773	1.0000	0.8281	0.8286

phenomenon of collaboration in the field of scientific research. However, we can conclude that the situation of collaboration of NCNST was better than CNSI.

Comparison of collaboration networks

For the sake of comparing the complete networks, we adjusted the time span from 2001 to 2013 for CNSI, in accordance with its founding time.

With the help of tools such as Sci2 (Science of Science) and Pajek, we got the collaboration networks features of NCNST and CNSI (Table 7). Two of these networks both have more than 3,000 nodes (authors) and 20,000 edges (co-authorships), which could be regarded as a large size networks. From visualization networks graphs Figs. 3 and 4, we can see that they are all tightly connected. However, CNSI is more scattered than NCNST and the largest connected component is smaller (Table 7). Furthermore, the clustering coefficient of NCNST is approximately 0.80 while CNSI's value is about 0.86; the average path length (APL) of NCNST is 3.21 and the value of CNSI is 3.98. With higher clustering coefficient and shorter APL, the two networks can be seen as small-world networks (Watts 1999; Fleming et al. 2007; Guan et al. 2014). In order to obtain a more accurate determination result, we will calculate the "small world quotient" (Uzzi and Spiro 2005;

Table 7 Collaboration networks features of NCNST and CNSI

Networks features	NCNST	CNSI
Nodes	3214	3173
Isolated nodes	0	1
Edges	25,378	20,363
Average degree	15.7922	12.8352
The largest connected component	3177	2995
Density	0.00491355	0.00404512
Diameter	7	9
Average path length (APL)	3.2062565	3.9822775
Clustering coefficient	0.800925037	0.857659156

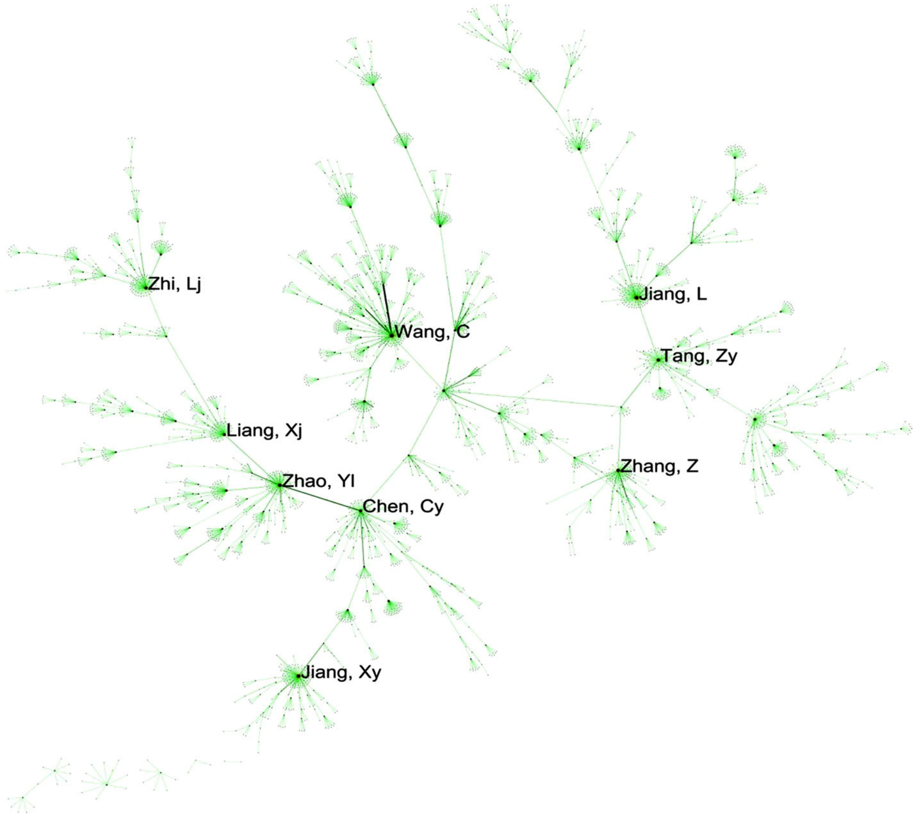

Fig. 3 Collaboration networks of NCNST

Cainelli et al. 2015) following Eq. (10). Where Q_{sw} represents the “small world quotient” and the “subscript a and r respectively indicate the actual and the equivalent random networks CC and APL, in terms of average degree and density” (Cainelli et al. 2015, p. 683).

$$Q_{\mathrm{sw}} = \frac{\frac{\mathrm{CC}_a}{\mathrm{CC}_r}}{\frac{\mathrm{APL}_a}{\mathrm{APL}_r}} \tag{17}$$

We create two random networks respectively equal to the collaboration networks of NCNST and CNSI in terms of the size (the same density and average node degree). Finally we get: $\mathrm{CC}_{\mathrm{rNCNST}} = 0.00254553$; $\mathrm{APL}_{\mathrm{rNCNST}} = 4.14041$; $\mathrm{CC}_{\mathrm{rCNSI}} = 0.00193139$; $\mathrm{APL}_{\mathrm{rCNSI}} = 4.54637$; and then $Q_{\mathrm{swNCNST}} = 406.311$; $Q_{\mathrm{swCNSI}} = 506.965$. As “the greater the Q_{sw}, (and particularly if the quotient is >1), the closer the structure of the network to a ‘small world’ structure” (Cainelli et al. 2015, p. 683), and $Q_{\mathrm{swCNSI}} > Q_{\mathrm{swCNSI}} \gg 1$, the collaboration networks of NCNST and CNSI all have small-world property and CNSI is more significant than NCNST. In addition, since small-world effect is tested on the aggregate network but some relationships may dissolve over time. Then we also tested this effect of two institutions for the two different periods (2004–2008 and 2009–2013). The results are $Q_{\mathrm{swNCNST2004}} = 56.79$,

Fig. 4 Collaboration networks of CNSI

$Q_{\mathrm{swNCNST2009}} = 145.21$, $Q_{\mathrm{swCNSI2004}} = 63.98$, $Q_{\mathrm{swCNSI2009}} = 138.86$. All of them are much bigger than 1. Consequently, it proved the conclusion above. Furthermore, we can also see that this effect is more significant over time for both institutions. Many researchers assumed that the structure of small networks was important particularly for knowledge generation and diffusion (Guan et al. 2014). Regarding this, CNSI is performing better than NCNST.

Numerous studies show that the majority of real-world networks are not random networks. A few nodes tend to have a large number of connections and others are not. If the degree is in line with power-law distribution, the networks are generally regarded as scale-free networks (Barabási and Albert 1999). Scale-free networks have severe heterogeneity because the nodes are unevenly distributed. A small number of nodes in the networks play the leading roles. Therefore, it is necessary to test whether the networks of the two institutions are scale-free networks.

Figure 5 shows that degree distribution of collaboration networks of NCNST and CNSI. The graphs are plotted in log–log scale (the log base is 10) with the degree on the X-axis, and the fraction of nodes on the Y-axis. Through regression analysis with the help of software Excel, we found the degree distribution functions of them respectively are: $P_{\mathrm{NCNST}}\ (K > k) \sim k^{-1.384}$ and $P_{\mathrm{CNSI}}\ (K > k) \sim k^{-1.537}$. It means their degrees strictly follow power-law distribution and the collaboration networks are scale-free networks (Barabási and Albert 1999).

According to the above analysis, the power-law distribution characteristics greatly improve the likelihood of the existence of nodes with high degree. Consequently, scale-free networks embody both robustness against random attacks and fragility against deliberate attacks. This has a great impact on network fault tolerance and anti-attack capability. Studies have shown that scale-free networks are highly fault-tolerant, but have poor anti-attack capability in terms of selective attack on the nodes that have high degree. In other words, high degree greatly weakens the robustness of the networks. If a malicious

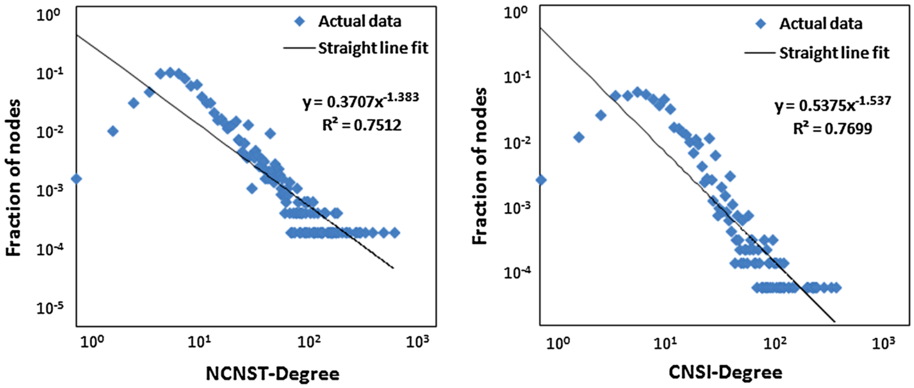

Fig. 5 Degree distribution of collaboration networks of NCNST and CNSI

Table 8 Top 10 authors with respect of their degree centrality of NCNST and CNSI

No.	NCNST		CNSI	
	Author	Degree centrality	Author	Degree centrality
1	**Wang, C**	**441**	Stoddart, Jf	248
2	Zhao, Yl	357	Tseng, Hr	225
3	Yang, Yl	293	Kaner, Rb	196
4	Chen, Cy	256	Yang, Y	171
5	Liu, Y	232	**Weiss, Ps**	**168**
6	Jiang, Xy	227	Zink, Ji	163
7	Tang, Zy	213	Gimzewski, Jk	162
8	Jiang, L	209	Teitell, Ma	161
9	Liang, Xj	189	Chen, Y	158
10	Han, D	180	Zhou, Zh	148

Note Wang, C and Weiss, Ps are the leaders of the two institutions

attack on a small part of high degree nodes happens, the network will be rapidly paralyzed. For this reason, NCNST and CNSI should pay more attention to the scientific researchers who have a high degree (Table 8). For example, Wang Chen (Wang, C) who has the highest degree centrality at NCNST, is the former dean of NCNST; and Paul Weiss (Weiss, Ps) with respect of the fifth highest degree centrality at CNSI, is the incumbent director of CNSI. Once they lose these talents, the collaboration networks will be seriously affected.

Comparison of knowledge networks

Based on processing the data of "ID (New ISI Keywords)", we extracted 4747 "keywords" from NCNST and 4285 "keywords" from CNSI. For the sake of comparison, we visualized them through visualization software VOSviewer (Figs. 6, 7) and listed the top 10 keywords with respect to their degree centrality (Table 9). From the overall knowledge networks, we can see the co-occurrence of knowledge elements (meta-knowledge or keywords) of the two networks. Those two are similar, but not exactly same. It can be seen that NCNST and CNSI have the same five keywords on this list. They are: *Nanoparticles,*

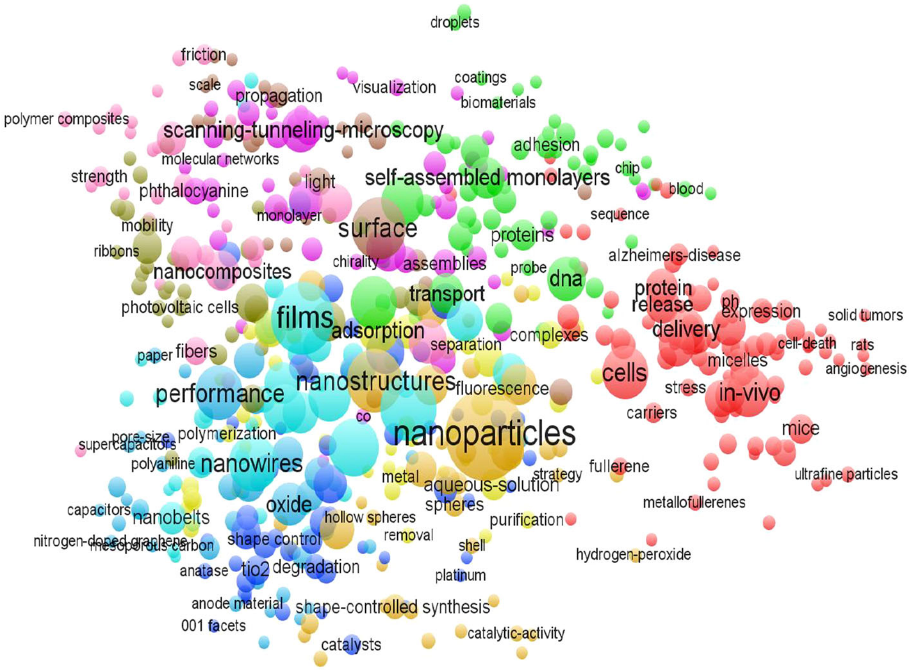

Fig. 6 Keywords co-occurrence of NCNST. *Note* The size of a dot reflects the degree of a keyword

Films, Surface, Growth and *In-vivo*. However, the degrees of these keywords of NCNST are generally higher than CNSI. The reason might be that NCNST published more papers than CNSI; nevertheless, it suggests that they have similar research directions in general.

In order to get a more accurate comparison result, we also calculated the *Cosine Similarity* between the two institutions. It is a measure of similarity between the two vectors composed by all keywords assigned to the institutions' publications. *Cosine Similarity* is defined using a formula (Kavyasrujana and Rao 2015):

$$\text{Similarity} = \cos(\theta) = \frac{A \cdot B}{\| A \| \cdot \| B \|} = \frac{\sum_{i=1}^{n} A_i \times B_i}{\sqrt{\sum_{i=1}^{n} (A_i)^2} \times \sqrt{\sum_{i=1}^{n} (B_i)^2}} \tag{18}$$

where A and B are the two vectors composed by all keywords assigned to NCNST and CNSI; n is the dimension of the vector which reflects the number of these keywords. The first step is to calculate and create the frequency of occurrence vectors for each institution. According to formula (18) and following the steps provided by Kavyasrujana and Rao (2015), we get the *Cosine Similarity* between NCNST and CNSI. It is 0.80. "The result of this is always between 0 and 1.The value 0 means 0 % similar and 1 means 100 % similar."(Kavyasrujana and Rao 2015, p. 188). Thus we can conclude that NCNST and CNSI are 80 % similar considering their research interests or topics.

Collaboration networks structures and the research performance

Dependent variables are: (1) the scientific output of researchers (the number of articles published in 2009–2013, represented by "works09"); (2) total citations of the articles

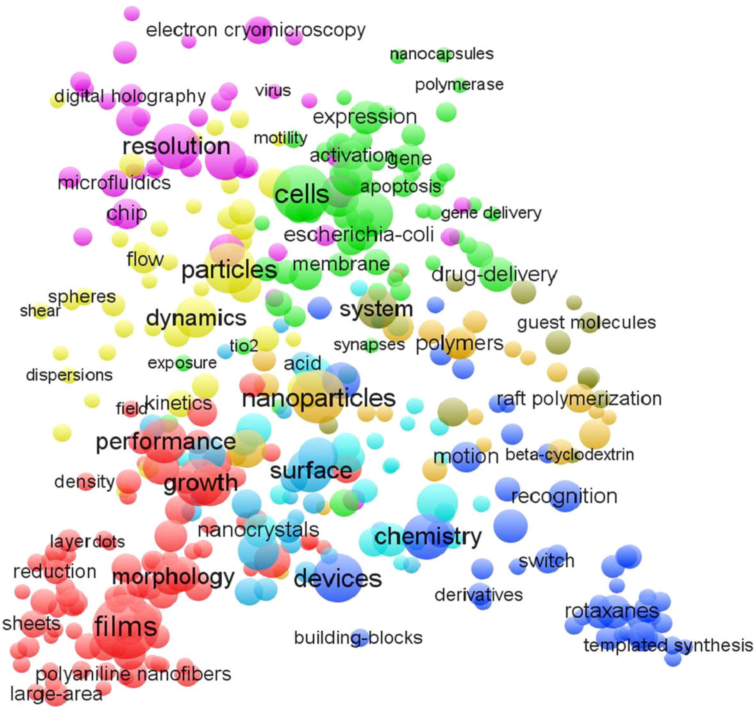

Fig. 7 Keywords co-occurrence of CNSI. *Note* The size of a dot reflects the degree of a keyword

Table 9 Top 10 keywords with respect of their degree centrality of NCNST and CNSI

NCNST		CNSI	
Keywords	Node degree	Keywords	Node degree
Nanoparticles	882	**Nanoparticles**	353
Films	546	Cells	342
Surface	521	**Films**	307
Growth	513	Particles	259
Nanostructures	509	**Growth**	255
Nanocrystals	397	Protein	254
Fabrication	387	**In-vivo**	253
Performance	386	**Surface**	249
Cells	383	Chemistry	248
In-vivo	369	Devices	247

Note NCNST and CNSI have the same five keywords that are marked in bold characters

published in 2009–2013. As noted above, older publications naturally have a longer period to be cited than the new ones. In order to control the 'age effect', we normalized the count of citations yearly. Then we summated the values of the year from 2009 to 2013 (represented by "Timecited09"). Independent variables are: (1) degree centrality (degree centrality of authors during 2004–2008, represented by "cendgree04"); (2) structural holes (structural holes of authors during 2004–2008, represented by "strucHole04"). According

Table 10 Descriptive statistics and correlation matrix

Variables	Mean	SD	1	2	3	4	5
1. Works09	4.26	10.75	1				
2. Timecited09	.11	.33	.857**	1			
3. Works04	2.70	4.57	.571**	.435**	1		
4. Cendgree04	11.54	12.87	.581**	.462**	.905**	1	
5. Struchole04	1.63	.18	.243**	.222**	.367**	.585**	1

** Correlation is significant at the 0.01 level (2-tailed)

to the current practice (Gonzalez-Brambila et al. 2013), we considered the count of past publications as the control variable. It refers to the scientific output of researchers (the number of articles published in 2004–2008, represented by "works04"). Since the variance is greater than mean for all variables (Table 10), we adopted the negative binomial regression to test the models. Descriptive statistics and correlation matrix are shown in Table 10.

Table 10 shows that the correlations between variables are all significant, and some variables have high correlation coefficient (e.g. 0.905 between works04 and cendgree04), it is necessary to examine if there is collinearity. Finally we got that the vif (Variance Inflation Factor) of "works04", "cendgree04" and "struchole04" was 6.15. Generally speaking, when $0 < \text{vif} < 10$, there is no multicollinearity; when $10 \leq \text{vif} < 100$, there is a strong multicollinearity; when $\text{vif} \geq 100$, there is a serious multicollinearity. Thus, we can exclude the problem of collinearity.

Table 11 reports the negative binomial regression results calculated by Stata software (http://www.stata.com/). Model (1) indicates that degree centrality has a significant impact on the scientific output. On the contrary, the impact of structural holes is not significant. Then we put the square of the degree centrality in the model [Model (2)] and found that degree centrality and scientific output had significant inverted-U shape relationship;

Table 11 Results of negative binomial regression (N = 894)

Dependent variable	Model(1) Works09	Model(2) Works09	Model(3) Timecited09	Model(4) Timecited09
Cendgree04	0.0491** (.016)	0.0763*** (.019)	.0217 (.016)	.0561*** (.018)
Struchole04	−.0295 (.450)	−.5551 (.488)	2.6660$^+$ (.942)	.9801 (1.010)
Cendgree04^2		−.0004*** (.0001)		−.0002** (.0001)
Works04	.0128 (.041)	.0327 (.046)	. − .0003 (.039)	.0039 (.033)
cons	.5967 (.519)	1.1859** (.703)	−7.0869*** (1.547)	−4.6963** (1.590)
Wald Chi-square	121.92	130.83	80.72	90.26
Log likelyhood	−1836.56	−1832.10	−271.05	−266.28

$^+$ 10 % ($p < 0.10$); ** 1 % ($p < 0.01$); *** 0.1 % ($p < 0.001$). The standard error is reported in parentheses meanwhile the significance of structural holes not changed. In addition, according to the changes of Log likelihood value, the model is improved. Following Model (1) and (2), we also tested the relationship between citations (research influence) and networks structures (degree centrality and structural holes). According to Model (3), degree centrality had no significant influence on citations, and the impact of structural holes on citations was not so significant either. When including the square of the degree centrality on the base of Model (3) in Model (4), the result was similar to Model (2). Degree centrality and citations had significant inverted-U shape relationship. Meanwhile, the impact of structural holes was still not significant. Although we tested the vif (Variance Inflation Factor) of "works04", "cendgree04" and "struchole04", we still removed the "works04" variable from the models to check that the results hold. Finally, we found it did not significantly affect the results.

The results revealed a significant inverted-U shape relationship between degree centrality and scientific output and scientific influence. Such relationship has been widely documented in many studies (McFadyen and Cannella 2004; Chen and Guan 2010; Rotolo and Messeni Petruzzelli 2013) which reflected that the inverted-U shape relationship not only existed in a special field (e.g. nanoscience and nanotechnology) but also in some other fields and all patent collaboration networks at country level. The result of this study proves that the inverted-U shape relationship has generalized practice significance: it is not only effective at the country level but also at the institutional level like the typical case in our study.

The result suggested that, in the initial stage, a higher degree centrality could facilitate authors to gain more knowledge and information from other authors; to enhance extensive knowledge sharing, knowledge transfer and knowledge creation, and then to improve scientific output or innovation performance. The correlation between the square of degree centrality and scientific output and influence passed significance test, which suggested the existence of a threshold effect between them. In real world, the appropriate degree centrality is conducive to enhancing innovation performance, whereas, as long as the centrality degree exceeds a certain point, it will be counterproductive. In this case, authors have to invest lots of energy to maintain this relationship and induce excessive internal friction. It goes smack against the creation of new knowledge and innovation activities, and inevitably leads to the decline of innovation performance. In this vein, we suggest that the administrators of institutions should stimulate their researchers who have a low degree centrality to extensively cooperate with others. The result did not give significant effect of structural holes either on scientific output or citations. In fact, the arguments in the existing studies are always inconsistent in this respect. Some scholars assumed that structural holes could enable researchers to benefit from autonomy in inventive activities in a collaboration network (Burt 1992, 2004; Fleming et al. 2007; Cainelli et al. 2015), while some others argued that structural holes had a negative impact on innovation performance (Podolny and Baron 1997; Ahuja 2000; Wang et al. 2014). Shipilov (2009) mentioned that structural holes may generate different performance results depending on several factors. Consequently, it is understandable that we failed to find any significant effect of structural holes.

Conclusions

In this paper, we mainly compared NCNST with CNSI—two representative institutions in nanoscience and nanotechnology field respectively from China and USA that are always conceived as the first two largest producers in the world. The main methods are social network analysis (SNA) as well as bibliometrics analysis and the dataset is derived from

"Web of Science Core Collection" supplied by Thomson Reuters. We finally came to the findings as follows.

1. The scientific output of both institutions grew fast especially in the last 5 years. This can be proven by the value of RGR and D_t. Meanwhile, the RGR of NCNST was higher than CNSI in most years and doubling time (D_t) was relatively shorter. The values of CI, DC, CC and MCC of NCNST were mostly greater than CNSI. Consequently, the situation of collaboration of NCNST was better than CNSI and it also performed better than CNSI in terms of the number of articles and authors. On the contrary, the citations and average citations of NCNST were mostly less than CNSI.
2. The authors of NCNST were more tightly connected than that of CNSI and the size of NCNST collaboration networks was also a little larger. These two networks all had small world properties, but the small world quotient (Q_{sw}) of CNSI was greater than that of NCNST. Furthermore, two collaboration networks were all scale-free networks that embodied both robustness against random attacks and fragility against deliberate attacks.
3. Knowledge networks of NCNST and CNSI were similar. They generally have similar research directions which can be proved both by keywords co-occurrence analysis and top 10 keywords with respect of their degree centrality.
4. Degree centrality had a significant inverted-U shape effect on scientific output and scientific influence. However, we failed to find that structural holes had any significant effect on scientific output and scientific influence.

Based on these findings, we can conclude that NCNST and CNSI are indeed comparable. NCNST had many advantages in terms of author and paper quantities, growth rate and the strength of collaboration but lost dominance in terms of research quality. This is in accordance with some other studies involving country level (Zhou and Leydesdorff 2006; Guan and Ma 2007; Leydesdorff and Wagner 2009; Guan and Wang 2010; Karpagam et al. 2011; Kostoff 2012). To some extent, this study proved those conclusions through investigating two specific institutions and filled the gap that no such research in the mainstream literatures. It also brought empirical significance for policy makers of state or government because NCNST and CNSI could be regarded as the leading institutions in nanoscience and nanotechnology field in their home country; especially both of them were derived from national programs. Comparative analysis of representative institutions can help decision-makers see specific details of the gap between them. They can draw the strong points of each other to offset its own weakness and then enhance and improve performance. Furthermore, the analysis framework could also be applied to other disciplines or areas.

Our study has limitations that are necessary to be pointed out for future research opportunities. First, based on the existing literature, we only compared part of measures of the two networks. This could be extended to examine some other measures in the future. Second, in statistical models, the count of citations was just normalized by age. It should be ideally normalized by sub-field, because citations rates may significantly differ even within nanoscience and nanotechnology. However, compared to country level, the size of the data from the specific institution is too small. Such a small amount of data hindered the analysis by sub-field.

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