Portrait of China's R&D activities in Nanoscience and Nanotechnology in bibliometric study

Nan Ma[1,2], Yi Zhao[1]

manan0613@gmail.com
1 Beijing Jiaotong University, Key Laboratory of Urban Transportation Complex System Theory and Technology, Ministry of Education, Beijing 100044, P.R. China
2 Healthcare and Science Business, Thomson Reuters, Unit 610, North Tower, Raycom Info Tech Park C No.2 Kexueyuan South Road, Haidian District Beijing 100190 China

Abstract
China has made great improvement in some critical scientific subject, like nanoscience and nanotechnology. This study explores the state-of-the-art developments of China in nanoscience and nanotechnology, as the previous study showed that China has become the second leading nation in terms of its share of "nano-prefixed" publications all over the world. Patent applications are also included in this study, as there are considerable efforts underway that aim to commercialise nanotechnology, and it is also an important aspect of R&D output. In particular, this study compares the rising pattern of nano-publication and nano-patents, to showcase the gap which lies between the knowledge base and technology base. Furthermore, this study investigates the research focus for both publications and patents in nanoscience and nanotechnology. The findings suggest that the strong presence of publications in MATERIALS SCIENCE, PHYSICAL CHEMISTRY and APPLIED PHYSICS are also in line with China's overall research focus; while there are also many inventions focused on novel formulations of pharmaceutical products which have recently applied in Chinese Traditional Medicine. Finally, the cross-analysis of top organizations and Derwent Classification indicates that the collaboration links between organizations are relatively weak, though their technologies are highly concentrated in some similar areas. Collaborative research is a double edged-sword which may either mutually enhance the research base, or damage to the competitive advantage in commercialization.

Introduction
Nanoscience and nanotechnology is a burgeoning field and discipline, attracting widespread attention in the international scientific community. Not only scientists and technology developers are intrigued by the fascinating opportunities of this emerging field, but also policy-makers believe nanotechnology to be one of the key technologies of the 21st century that will create new markets and thus prosperity (Heinze, 2004).
Early in the middle of 1980s, the Chinese Academy of Sciences (CAS) initiated support on the development of Scanning Probe Microscopes (SPM) and other scientific issues at the nanometer scale (Bai, 2005). It was reported that from 1990 to 2002, nearly 1000 projects related to nanomaterial applications with a total fund of $27 million were implemented in China. In addition, during this period, NSFC granted nearly 1,000 small-scale projects in related areas (Bai, 2005). The total funds supported by the government for nanoscience and nanotechnology researches have reached about US$7 million during the past 10 years (Bai and Wan, 2003).
On the other hand, prominent achievement has been obtained in the basic research of nanoscience in China. The 2001 review report on nanoscience and nanotechnology by APEC ranks China as No.3 in the world in terms of scientific publications. China has become a major player in nanotechnology (Zhou and Leydesdorff, 2006).

Data and Methodology
Over the past few years, several attempts have been made to study nanoscience and nanotechnology in a bibliometric manner (Braun et al., 1997; Kostoff, 2004; Zhou & Leydesdorff, 2006; Meyer, 2010). In comparison to other fields of science and technology, there is no readily available subject category or classification system for the nanoscience and

nanotechnology. Furthermore, no agreements have been made on the definition of nano-community in the above mentioned studies. In this respect, this study adopted a set of "nano" prefixed keywords which are closely related with nanoscience and nanotechnology.

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NANO* NOT (NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSECON* OR NANO SECON* OR NANO-
SECON* OR NANOGRAM* OR NANO GRAM* OR NANO-GRAM* OR NANOMOL* OR NANOPHTALM* OR
NANOMELI* OR NANOGETEROTROPH* OR NANOPLANKTON* OR NANOKELVIN* OR NANOCURIE* OR NANO
CURIE* OR NANO-CURIE* OR NANOS OR NANOS1 OR NANOPROTO* OR NANOPHYTO* OR NANOFLAGEL*
OR NANOBACTER* OR NANO BACTER* OR NANO-BACTER* OR NANOSPRAY* OR NANO SPRAY* OR
NANO-SPRAY*)
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This paper presents the results of a bibliometric study that compared publication and patenting activities of China in nanoscience and nanotechnology. In details, the study exploits the literatures from Web of Science and the patents from Derwent World Patents Index, both provided by Thomson Reuters. For the literatures, the author addresses of publications are limited to "Peoples R China"; while for the patents, the data field of priority countries is chosen to match with "CN" which can approximately represent those granted patents and patent applications applied by Chinese organizations or residence. The publication and patent database include 60,505 and 24,032 items separately, both cover the time period 2000~2009.

Results

Total trends and descriptive analysis of China's nanoscience and technology

The first section briefly describes the growth of the occurrence of the prefix "nano" in titles of scientific publications and patents affiliated to China from 2000 to 2009. Based on the prepared data set, the numbers and growth trends of "nano-title" publications and patents are illustrated in the following Figure 1.

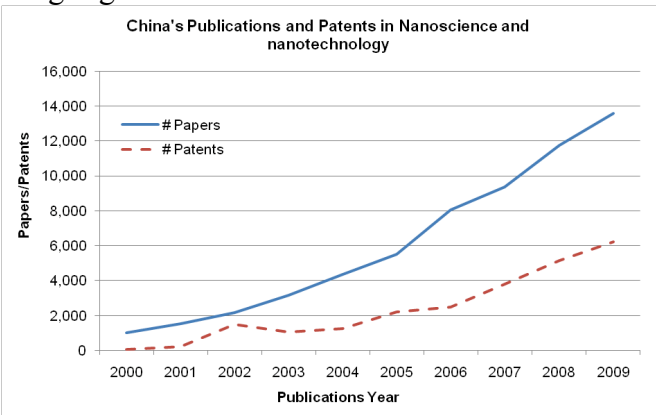


Figure 1. China's research papers and patents in Nanoscience and nanotechnology during 2000~2009

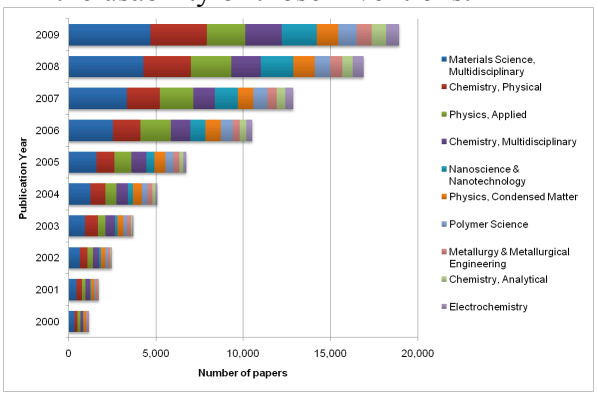
The upward trend in the above figure reveals the fast development of this emerging discipline during the past decade. China's galloping growth in nano-papers attracts much of the world's attention just as its fascinating national economy. While there was little patenting activity in the 1990s in the variety of fields, most notably in analysis and measurement, nano-patenting has increased substantially from 2001. It is shown in Fig.1 that China's sustained increase in nano-related technologies is also remarkable as regards the nano-prefixed patents.

As comparing two increasing curves of both nano-papers and nano-patents, one can find that the increase of nano-papers is stronger than that of nano-patetns, which in another way can tell us that there are still large gap between knowledge base and technology base, and the linkage between the two sides hasn't been well established yet. In other words, there still need much power to accelerate transformation from basic research to applied technologies, leading thereby to industry productivities and social benefits.

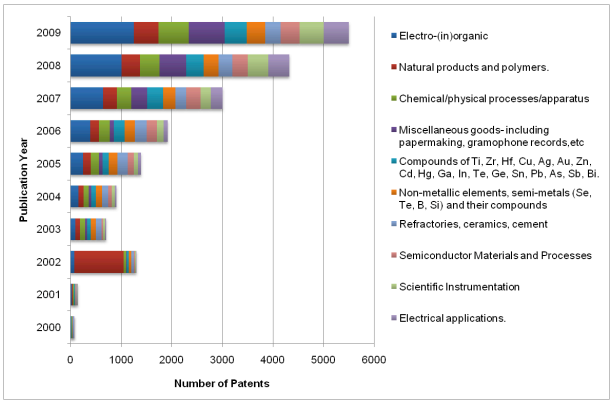
Research and innovation focus of nanoscience and nanotechnology in China

To further investigate the research and innovation status of China's nanoscience and nanotechnology, the Subject Categories of research papers and Derwent Classifications of patents are applied to highlight the active areas and differentiate the focuses in research and innovation activities in nanoscience and nanotechnology.

The Subject Categories were extracted from Web of Science, which is originally assigned to journals and has altogether 256 subjects covering all aspects of science, social science, arts & humanities. On the other hand, Derwent Classifications were extracted from Derwent World Patents Index, which is assigned by industry experts to each patent application to better reflect the usability of those inventions.



(a)Distribution of subject categories for research papers



(b)Distribution of Derwent Classification for patent applications

Figure 2 Comparison of research focuses in Nanoscience and nanotechnology

As shown in Fig.2, the top 10 Subject Categories of research papers and Derwent Classifications of patent applications are provided in a trend analysis manner. If we look at the focusing areas of research papers, we can find that MATERIALS SCIENCE, PHYSICAL CHEMISTRY and APPLIED PHYSICS are the main areas where 1/2 of total research papers lie in. This finding is also in line with the report in Global Research Report: China (2009) that, China's overall research concentration is in the physical sciences and technology, with Materials Science, Chemistry and Physics predominant. The papers in the area of NANOSCIENCE & NANOTECHNOLOGY only accounts for less than 1/10 of total publications, which on one hand indicated that nanoscience and nanotechnology is strongly characterized by interdisciplinary, and on the other hand self-evidenced the rationality of search strategy in the data-collection phase.

When one take a look at the top 10 Derwent Classifications of patent applications, it can be seen that ELECTRO-(IN)ORGANIC is the biggest area where nanotechnology find the applications in. Besides, one can also interestingly find that, there are substantial amount of patent applications in the area of NATUAL PRODUCTS AND POLYMERS, peaked in 2002. After a quick review of total 2,617 patent applications in this area, it can be found that many inventions are focused on novel formulations of pharmaceutical products which have recently applied in Chinese Traditional Medicine. This is China's traditional core strength combined with the most cutting-edge technology, encouraging more and more new applications of nanotechnologies. For a closer analysis for China's areas of concentration in nanoscience and nanotechnology, one can also find that MISCELLANEOUS GOODS also registering a strong presence in the innovation activities of nanotechnology in China. Thus, it is interesting to see that more and more nanotechnologies have come into consumer products in our everyday life.

Coactivity of research institutes in nanoscience and nanotechnology

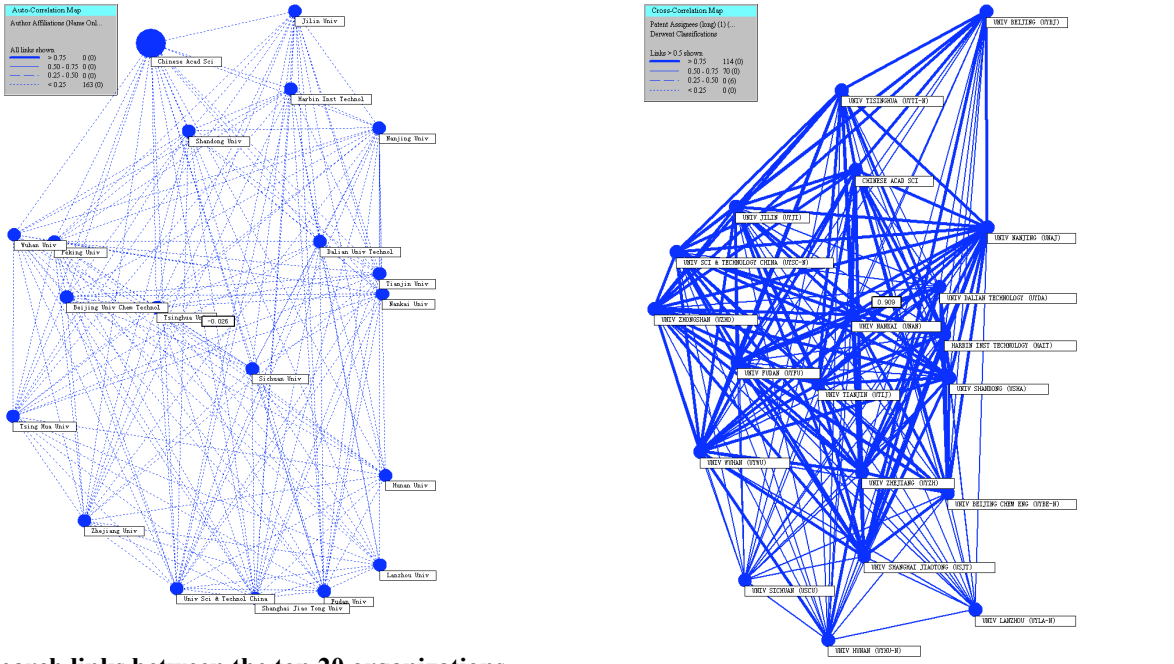
Policy-makers in many countries emphasize the importance of non-publication output of university research. Increasingly, policies are pursued that attempt to encourage entrepreneurial activity in universities and public research institutes. Apart from generating spin-out companies, technology licensing, and collaborative research, attention is focused on patenting activities of research organizations.

CHINESE ACADEMY OF SCIENCE occupies a predominant place in Table 1, which represents a selection of top 20 research institutes that have most number of publications together with their notably high numbers of patents during 2000~2009. The list is not a complete reflection of just the top organizations, but has been selected to give a fuller flavour to the concentration of research backbones in China's nanoscience and nanotechnology. Besides, UNIV SCI & TECHNOL CHINA, PEKING UNIV and LANZHOU UNIV stand out for the large ranking differences between papers and patents; indicating that these institutions are on the one hand more basic research-oriented, and on the other hand lack of energy in technological innovation activities compared with other organizations.

Table 1 Publication and patenting activities of top institutions in China

Research Institutions	Papers		Patents	
	Counts	Rank	Counts	Rank
CHINESE ACAD SCI	13500	1	1592	1
TSINGHUA UNIV	3414	2	738	3
UNIV SCI & TECHNOL CHINA	2815	3	90	34
NANJING UNIV	2393	4	282	9
ZHEJIANG UNIV	2291	5	606	4
PEKING UNIV	2139	6	144	25
JILIN UNIV	2001	7	162	19
SHANGHAI JIAO TONG UNIV	1774	8	519	5
FUDAN UNIV	1761	9	355	7
SHANDONG UNIV	1358	10	134	26
WUHAN UNIV	1092	11	147	24
TIANJIN UNIV	988	12	251	10
NANKAI UNIV	966	13	148	22
HARBIN INST TECHNOL	963	14	197	15
LANZHOU UNIV	955	15	17	177
HUNAN UNIV	938	16	76	40
ZHONGSHAN UNIV	860	17	189	16
SICHUAN UNIV	828	18	178	17
DALIAN UNIV TECHNOL	776	19	83	35
BEIJING UNIV CHEM TECHNOL	766	20	242	13

For a further analysis of the research activities in these top 20 organizations, we turned to investigate the collaborative relationship and technology similarity of publications and patents respectively. In details, the collaborative relationships were built on the publication co-authorship, and the technology similarities were established via the co-occurrence of Derwent Classifications of patents filed. Both the relationships are then mapped using Thomson Data Analyzer for better demonstration; where the area of dots represented the publication counts and the thickness of lines indicate how strong the two entities are linked together.



a)Research links between the top 20 organizations **b)Research closeness between the top 20 organizations**

Figure3 Research links and closeness between the top 20 organizations

Figure 3 represents an overview of how the top organizations are collaborated or related in nanoscience and nanotechnology. Immediate evidence in Fig.3 (a) is that the collaborations between these organizations are equally distributed, with CHINESE ACAD SCI centred in the middle as the most active player among the target organizations. However, one can find that the top 20 institutions are sparsely connected, given the high level of productivities. When looking at Fig3. (b), it is interesting to find that these organizations actually share a lot in common in terms of technology classification.

An interesting finding between the comparisons of Fig.3 (a) and Fig.3 (b) is that, the top 20 organizations are weakly linked in research activities, while their technologies are highly concentrated in some similar areas. This will be both an opportunity for these organizations already devote themselves heavily in this field, and would like to collaborate with others in its new research venture; and a challenge as the fruits of these research efforts have been applied to innovation process and product. Thus, to collaborate and form joint effort or to compete and take the lead is still a big outstanding issue for these top organizations.

Concluding Remarks and Further Discussions

Research of nanoscale phenomena has increased over the last decade across the world. This research has presented a summary of bibliometric research in China happened in the world of nanoscience and nanotechnology. Overall, different growing pattern was observed in publication and patenting activities. This reflects the large gap between the knowledge base and technology base of China in nanoscience and nanotechnology, which still requires much driving force to accelerate the transformation from basic research to applied technologies.

The sub-fields analysis of nano-patents suggests that Chinese Traditional Medicine has been combining with the most cutting-edge technology, thereby encouraging more and more new applications of nanotechnologies in the traditional industrial area.

The study has also presented data that gives an idea about which organization are most active in terms of nano-publications together with nano-patents filed. It is interesting to find that the top organizations are weakly linked in research activities, while their technologies are highly concentrated in some similar areas. To collaborate and form joint effort or to compete and take the lead is still a big outstanding issue for these top organizations.

Obviously, there are still many limitations and restrictions in this exploratory study. This study did not look further into the citation links between publications and patents. Neither did it explore the difference of citation impact for the organizations which file more patents than others. These issues open up a wide field for the future research.

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