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China's emerging presence in nanoscience and nanotechnology A comparative bibliometric study of several nanoscience 'giants'

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Abstract

This paper aims to provide an integrated bibliometric analysis of the knowledge base of nanoscience and nanotechnology in the Chinese research community. For comparative purposes, the results are benchmarked against the findings from four other major nations: France, Germany, Japan, and the USA. It is found that China is productive in nanoscience as far as publication activity is concerned. The analyses of collaboration and institutional patterns enable us to identify the active collaborative networks and productive research institutions among the five countries. Finally, analysis of the citation share and certain surrogate indicators shows that the Chinese scientific community needs to work on improving its research impact.

Keywords: Nanoscience and nanotechnology; Publications; Citations; Bibliometric study; Theil's index

1. Introduction

Nanoscience and nanotechnology is a burgeoning field, attracting widespread attention in the international scientific community. Not only are scientists and technology developers intrigued by the fascinating opportunities of this emerging field, but policy-makers also believe nanotechnology to be one of the key technologies of the 21st century that will create new markets and thus prosperity (Heinze, 2004).

Since 2000, the US administration has invested considerable resources in the National Nanotechnology Initiative (NNI) for the exploration of nanoscale phenomena and the development of useful devices and structures (Heinze, 2004). The Japanese Government has listed "Nanotechnology & Material Science" as one of the four priority areas in their Second Science and Technology Basic Plan (Anon., 2007). Analogously, China's State Council (2006) has identified "Nanoscience and Nanotechnology" as one of four major fields in science research in its medium and long-term plans for science and technology development (http://www.people.com.cn, 9 February 2006).

This paper analyses the overall development in this novel field by studying the scientific publications indexed by ISI databases. It provides an integrated bibliometric study of the knowledge base of nanoscience and nanotechnology in the Chinese research community, including comparisons with four other major counterparts. In addition, the paper presents the history and the development of nanoscale research activities among the outstanding research institutes, and their roles and influence in international collaborative networks. The results show that the Chinese research community should not be overly optimistic, despite the large number of publications in the field. To move forward and improve the overall competitiveness in the field of nanoscience and nanotechnology, it is evident that

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China needs to improve its now-limited research influence.

2. Data and methodology

Bibliometric quantification is an effective way to show the emergence and development of a new technology (Braun et al., 1997). Due to the limitation of accessibility to specialized databases, we accessed the Web of Science SCI Expanded database as our data source, since it is a widely accepted database covering most of the important influential journals in natural and medical science.

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; Meyer and Persson, 1998; Zhou and Leydesdoff, 2006). In comparison to other fields of science and technology, there is no readily available subject category or classification system for nanoscience and nanotechnology. Furthermore, no agreements have been made on the definition of the nano-community in the above-mentioned studies. The only way to approach "nanoscience and nanotechnology" in a bibliometric respect appears to be through keywords. In this respect, the following search string has been used:

NANO* *NOT* (NANO2, NANO3, NANO4, NANO5, NANOSECON*, NANO SECON*, NANO GRAM*, NANOGRAM*, NANOMOL*, NANOPHTALM*, NANOMELI*, NANOGETEROTROPH*, NANOPLANKTON*, NANOKELVIN*, NANOCURIE, NANO CURIE, NANOS, NANOS1, NANOPROTO*, NANOPHYTO*, NANOFLAGELLATE*).

The search strategy was determined based on some earlier studies (Braun et al., 1997; Glänzel et al., 2003; Schummer, 2004). The main idea was to search for papers with a "nano" prefix yet exclude some situations where "nano" is used as a prefix. This was done to uncover, from the contents, those citations that would probably be true nanoscale research.

Based on the current practices in scientometrics, we have limited the analysis to articles, reviews, letters, and notes. The selection of the five countries, China, France, Germany, Japan, and the USA, is based on their leading positions in global research on nanoscience and nanotechnology. According to our current database, the sum of nano-publications produced by these five countries accounts for more than half of the world's total.

3. Analyses and results

3.1. The publication profile

In order to show the historical development of the last two decades, we collected data for the five aforementioned countries from 1985 to 2004 (Fig. 1). In the previous literature, Braun et al. (1997) have already signalled the exponential growth in scientific publications with a prefix of "nano".

Fig. 1 provides a dynamic picture of the world share of nano-publications from each country. Since 2002, China has produced the second largest number of nano-

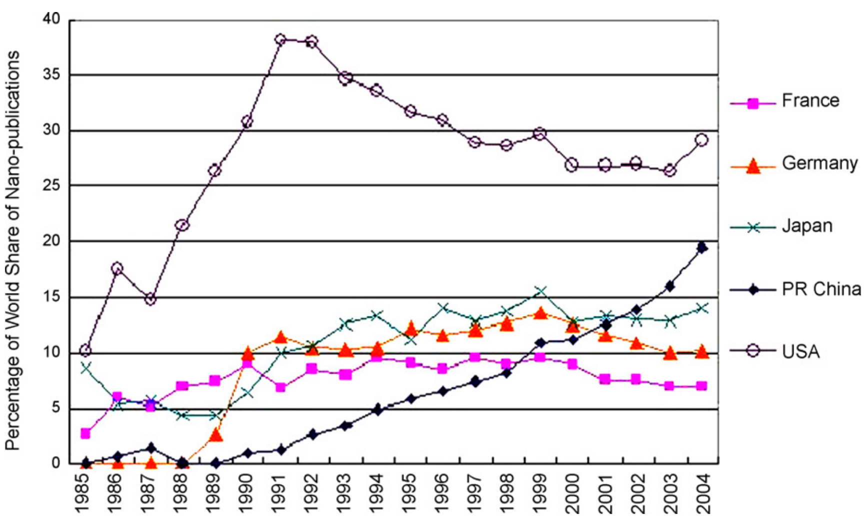

Fig. 1. Percentage world share of nano-publications.

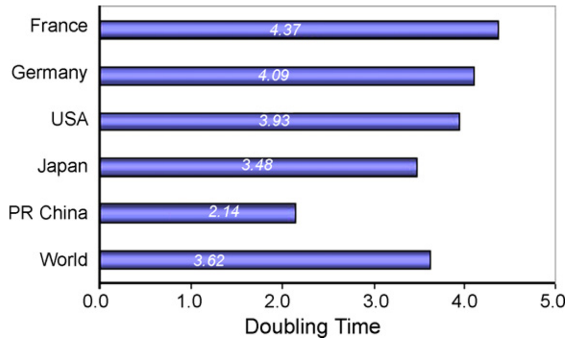

Fig. 2. Doubling time of nano-publications during 1995–2004.

Table 1
International co-publications of five selected countries in two sub-periods, 1985–1994 and 1995–2004

Country	1985–2004		1985–1994		1995–2004	
	Papers	Share (%)	Papers	Share (%)	Papers	Share (%)
France	4589	43.13	219	23.32	4370	45.05
Germany	6236	41.79	261	23.86	5975	43.21
Japan	3730	21.02	120	9.42	3610	21.92
PR China	2764	16.43	49	14.45	2715	16.48
USA	9391	24.48	474	12.20	8917	25.86

publications. In addition, China's sustained increase is remarkable, as it has been the only country to have its number of publications in the field grow exponentially, while the others show a decreasing trend over the last two decades. Japan has surpassed Germany by taking the second position since 1996. The number of publications from the USA decreased from 1993 to 2000, but the indicator shows its relative stability thereafter.

Considering the transformative change of publications in nano-research in the late 1990s, we examined the growth trends for the period of 1995 to 2004. As expected, the nano-publications in all five countries increased exponentially with $R^2 > 0.9$. In this case, we calculated the indicator of doubling time during 1995–2004 according to Rousseau and Jin's (2005) definition (Fig. 2). The number of China's nano-publications has doubled every 2.1 years during 1995–2004, indicating a much faster growth rate than the four other countries, as well as the world's, average.

China's rapid growth rate in nano-research is related to the increased funding for nanoscience and nanotechnology (Brahic, 2005). It was reported that the total funds granted by the Chinese government have already reached about $ 27 million during 1990–2002, and are expected to be increased further (Bai, 2005). Besides, the metrics for evaluating the performance of both individuals and organizations have also changed to boost the publication activities, especially those in the SCI journals.

3.2. The collaboration profile

3.2.1. International versus indigenous papers

The number of papers published in international journals and conferences, and their share in the total national publication output, serve as basic indicators of international co-authorship and scientific collaboration. Considering that the Chinese research community was relatively primitive in the 1980s but has developed rapidly over the recent decades, we collected the numbers and percentages of internationally co-authored publications produced from the five countries during the period of 1985–2004, and the two sub-periods 1985–1994 and 1995–2004, shown respectively in Table 1. From this table, one can see in greater detail the differences between countries as well as their development. The resulting plot shows that China's involvement in the international collaborative network still remains at a low level, for the percentage of international co-publications did not increase as much as the four other countries.

Here, foreign collaborative links are calculated in terms of the method used by Basu and Vinu Kumar (2000). The top 25 frequent collaborative links between pairs of countries are listed in Table 2. The results from this Table indicate that the five countries in our present study are also the major partners with each other in the international collaborative network. The USA is the first choice for the four other countries to cooperate with. China has followed Germany and Japan to become the USA's third largest partner in nanoscience research.

3.2.2. Contribution of international collaboration to the research impact

To test whether international collaboration has a positive effect on the impact of papers, the 'independent samples *t*-test' was applied to test the equality of citation means for indigenous and international papers statistically. The mean difference is produced by calculating the citation mean of indigenous papers minus that of international papers.

In Table 3, it seems that China has benefited greatly from international scientific co-publications in improving the research impact, since its citation mean of international papers is significantly higher than that of its indigenous papers. As for developed countries like the USA, international collaboration even has some negative effect on the impact, for the citation mean of international

Table 2
Collaboration links between pairs of countries

Collaborators	Countries				
	France	PR China	Japan	Germany	USA
USA	817	824	1187	1491	–
Germany	733	396	394	–	1491
Japan	218	569	–	394	1186
PR China	121	–	588	396	824
France	–	121	218	733	817
England	373	134	264	449	743
Canada	107	109	91	125	638
Russia	327	37	215	760	559
South Korea	46	131	313	80	522
Italy	508	42	97	309	448
Spain	421	32	64	250	361
Switzerland	249	15	73	427	357
Israel	87	50	31	137	298
The Netherlands	108	31	67	250	252
India	68	22	137	165	244
Brazil	123	24	66	82	215
Sweden	59	55	56	195	213
Belgium	255	36	29	129	209
Mexico	58	12	54	60	203
Taiwan	9	62	48	25	192
Australia	48	101	114	111	191
Poland	219	9	83	251	187
Singapore	2	177	29	21	145
Denmark	32	16	36	104	139
Austria	90	14	26	262	126

Note: Sorted in descending order of USA data column.

papers is significantly lower than that of indigenous ones. Consequently, international collaborations in academic research could increase mainstream connectivity and international visibility for the peripheral countries, just as previously suggested by Bordons et al. (1996), but this is not necessarily true for the U.S.

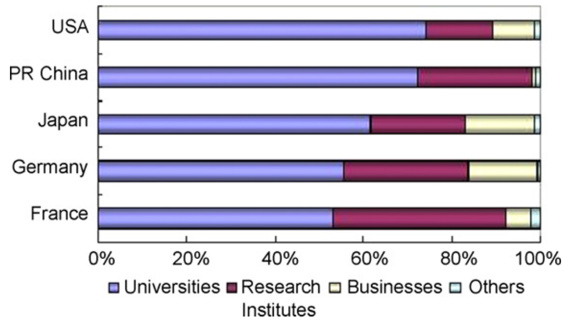

Fig. 3. Percentage share of each type of institution involve.

3.3. The institutional profile

We provide, in Fig. 3, the shares of publications from universities, research institutes, businesses, and other types of institutions included in 1985–2004. Similar to the other four countries, universities are the largest shareholders, while research institutes also make a considerable contribution to Chinese nano-publications. Enterprise research contributes only 0.5% to the Chinese nano-publications, which is well below the result from the other four countries.

We have then calculated the number of publications affiliated with each institution in the five countries and listed the top 15 most prolific ones in Table 4. China has taken one third of the top 15 positions among prolific institutions, and the Chinese Academy of Science ranked first among the five countries with a total of 4541 publications. It seems that China has effectively used its public-sector research potential to boost the research activities in the country.

Table 3
Independent samples *t*-test of citation means

Country		Levene's test for equality of variances		*t*-Test for equality of means			
		F	Sig.	*t*	Sig. (two-tailed)	Mean difference	S.E. difference
France	A	1.022	0.312	−0.158	0.874	−0.112	0.709
	B			−0.155	0.877	−0.112	0.727
Germany	A	0.022	0.882	0.846	0.397	0.529	0.625
	B			0.834	0.404	0.529	0.634
Japan	A	4.951	0.026	−1.488	0.137	−1.145	0.770
	B			−1.870	0.062	−1.145	0.612
PR China	A	109.483	0.000*	−8.783	0.000*	−2.428	0.276
	B			−6.402	0.000*	−2.428	0.379
USA	A	67.373	0.000*	7.222	0.000*	4.282	0.593
	B			7.331	0.000*	4.282	0.584

Note: A, equal variances assumed; B, equal variances not assumed; for the items marked with a "*", the variances (means) are significantly different between groups.

Table 4
Top 15 most prolific institutions in the field of nano-research around the world

Institutions	Papers	Affiliated country
Chinese Acad Sci	4541	PR China
CNRS	1769	France
Univ Paris	1768	France
Tohoku Univ	1709	Japan
Osaka Univ	1576	Japan
Univ Tokyo	1438	Japan
Univ Sci & Technol China	1321	PR China
Tsing Hua Univ	1210	PR China
Univ Illinois	1196	USA
Univ Calif Berkeley	1170	USA
MIT	1063	USA
Nanjing Univ	982	PR China
Tokyo Inst Technol	974	Japan
Peking Univ	973	PR China
Kyoto Univ	878	Japan

Table 5
Summary of the citation analysis

	CPP	Percentage of none-cited papers		Top 1% of highly cited papers	
		Total	Percent	Total	Percent
France	11.57	2277	21.40	77	7.85
Germany	12.40	2882	19.31	114	11.62
Japan	9.34	4563	25.72	88	8.97
PR China	4.62	6329	37.63	17	1.73
USA	18.96	6245	16.28	685	69.83

Note: CPP denotes the number of citations per paper.

3.4. The citation profiles

3.4.1. Summary

China's total citation rate is still low compared with citation rates for other nations (Jin and Rousseau, 2004). Fig. 4 provides the percentage share of citations of the five countries in a 10-year citation window from 1995 to 2004. The self-citations are not excluded from the total citations due to our constrained facilities and human resources.

It is indicated in Fig. 4 that China is the only country to have a sustained increase in the percentage share of citations, and fits the exponential growth with $R^2 > 0.9$. A similar conclusion about the Chinese publication system can also be found by using the percentage of world share of citations in all disciplines provided by Leydesdorff and Zhou (2005). But on the aggregate level, China is still the last country in terms of its percentage of citation share during 1995–2004. Other countries like Germany and Japan show the same trends on this indicator.

The indicator of CPP (citation per publication) in Table 5 suggests that the average citation rate of China only amounts to half of Japan's or one-fourth of the USA's average citation rate. Since the indicator of top 1% of highly cited papers is considered to be one of the most important measures of a country's influence in the scientific community (King, 2004), it may be concluded from the indicator of percentage of none-cited papers and top one percent of highly cited papers that China still suffers from low visibility of research influence. In contrast, the USA is far beyond the other counterparts, and takes almost 70% of top one percent of highly cited papers, though its world share of nano-publications is only 30%.

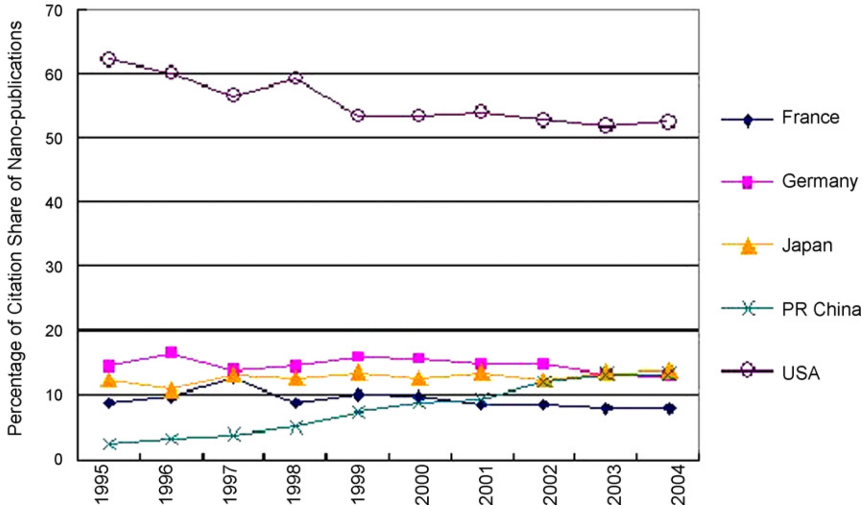

Fig. 4. Percentage citation share of nano-publications.

3.4.2. The inequality measure

The Theil's entropy Index is applied to the investigation of citation inequality in detail. Define y as a vector containing the values of all items $y_1, y_2, \ldots, y_i, \ldots, y_n$; $y_i \in \Re$, where n represents the number of units in the population. Theil's entropy Index (Theil, 1967) is calculated as: $T(y) = (1/n)\sum_{i-1}^{n}(y_i/y)\log(y_i/y)$. $T(y)$ is then decomposed into intra-national and international inequalities as

$$T(y) = T_{\mathrm{w}} + T_{\mathrm{b}} = \sum_{g=1}^{G} w_g T(y_g) + T(\bar{y}_1 e_1, \ldots, \bar{y}_G e_G),$$

$$w_g = \left(\frac{n_g}{n}\right)\left(\frac{\bar{y}_g}{\bar{y}}\right)$$

where G is the number of sample groups, e_g a vector with dimension n_g that contains all unit elements, and all the items with suffix g imply the same meaning in the gth subgroup. T_{w} is the within group inequality, and T_{b} is the between group inequality.

Based on this algorithm, we calculate the Theil's entropy index of the total citation population. The population's total inequality measure is then decomposed into five countries' within-country inequality, as well as the between-country inequality.

It can be conclude from Fig. 5 that the USA is the biggest contributor to the total citation inequality. Actually, the citation patterns in the USA can be mainly assigned into two distinct groups: the most influential ones and the unattended ones. Due to the limited publication population and less highly cited papers, the within-country inequalities of Germany, France, and Japan contribute much less, compared with the USA, to the total inequality. China contributes least to the total citation inequality, with a large number of less- and non-cited papers. As the publication output increases over the coming years, we may expect the citation levels to become more long-tailed, with a lower value of inequality.

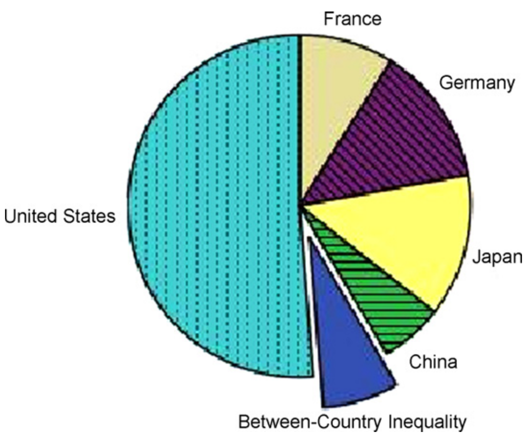

Fig. 5. Theil's index of citations in five countries.

4. Concluding remarks

This paper shows that research activities on nanoscale phenomena have increased over the last two decades around the world. We have seen how China has emerged as one of the major contributors to this emerging field. Indeed, it is the only country where both the volume of publications and the world share have kept growing exponentially over the last 20 years. However, China's research community is still only a small part of the larger international scientific network. It may also be inferred from the *t*-test that China has benefited greatly from international scientific collaborations in improving the impact of its research. Given the institutional structure of Chinese science system, it is astonishing to see that the Chinese Academy of Science has become the dominant institution in the five countries with a total publication output of 4541 nano-papers. The evolution of China's percentage share of citations also demonstrates the recent and continuous growth of China's research impact in the field of nanoscience. Further analyses of citation rates and relative citation performance have shown that China has scope to improve its research impact, as it currently lacks well cited papers and papers that have a significant impact. The percentage share of highly cited papers is relatively small in comparison with the much higher share of international publications. In short, Chinese nanoscale researchers are confronted with a challenge to improve their research quality as well as a challenge to increase funding levels for this emerging field.

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