

Nanotechnology publications and citations by leading countries and blocs

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Abstract This article examines the relative positions with respect to nanotechnology research publications of the European Union (EU), the United States (US), Japan, Germany, China, and three Asian Tiger nations (South Korea, Singapore, and Taiwan). The analysis uses a dataset of nanotechnology publication records for the time period 1990 through 2006 (part year) extracted from the Science Citation Index obtained through the Web of Science and was developed through a two-stage modularized Boolean approach. The results show that although the EU and the US have the highest number of nanotechnology publications, China and other Asian countries are increasing their

publications rapidly, taking an ever-larger proportion of the total. When viewed in terms of the quality-based measure of citations, Asian nanotechnology researchers also show growth in recent years. However, by such citation measures, the US still maintains a strongly dominant position, followed by the EU.

Keywords Nanotechnology publication · Bibliometric analysis · Citation analysis · Country comparison · Nanoscience · International perspective

Introduction and approach

There has been much interest in the positioning of countries relative to one another in scientific performance, particularly in emergent fields such as nanotechnology (Huang et al. 2003; Hullmann and Meyer 2003; Huang et al. 2005; Kostoff et al. 2006; Miyazaki and Islam 2007). Much of this analysis emphasizes publication counts and impacts as measures of research strength. Given the dynamic development and expansion nanotechnology research, it is useful to continually update and reassess international scientific performance. In so doing, it is very important to distinguish quantity and quality, the latter of which is often measured through citations. Drawing on a newly constructed and comprehensive dataset of global nanotechnology publications, this article presents an updated analysis that examines both quality

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and quantity in nanotechnology research by leading large countries and regions.¹ The results will show that the United States (US) remains the single largest national producer of nanotechnology scientific publications, although in the mid-1990s the European Union multi-national bloc (EU27) surpassed the US in terms of an aggregate count.² The dramatic rise of China in terms of publication counts is also noted. However, quality-related measures place the US in an even stronger position in the nanotechnology field.³

The results presented here are derived from a dataset of publications developed using the definition of nanotechnology and the data-cleaning methods described in Porter et al. (2007). To operationalize the definition of nanotechnology, we used a two-stage modularized Boolean approach.⁴ The first stage of our

¹ Kostoff et al. (2007) also present national nanotechnology publications comparisons. We differ here in considering leading countries and blocs of special interest, and addressing total citations as well as publications. Kostoff et al. (2007) do limited national ranking based only on share of 1998 papers with >120 cites and 2002 papers with >79 cites—with the particularly interesting finding that China's share of most cited papers increases from 1.4 to 5.8% in that span.

² In this article, the European Union is taken to comprise the 27 member countries (EU27) at the time we undertook the analysis. These countries are: Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, the Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, and the United Kingdom.

³ Although the focus in the present article is on large countries and blocs, we note that a few individual highly-developed small countries (mostly in Europe, including Switzerland and the Netherlands) have comparable or higher normalized quality impact factors in nanotechnology than the US, although their scale of output is far less.

⁴ Our approach builds upon prior experience in developing a large-scale bibliometric database of nanotechnology publications (as discussed in Heinze et al. 2007). In further refining our method, we reviewed a number of alternative nanotechnology search strategies, including strategies developed at UCLA's Nanobank (Zucker and Darby 2005) and in Europe (Zitt and Bassecoulard 2006), and consulted with several experts in nanotechnology and bibliometrics. We decided on a two-stage Boolean search rather than the bootstrap or lexical clustering approaches used by these colleagues, judging that this two-stage method provided the capability to fine-tune the search algorithm to ensure precision and timeliness. As we implemented our search strategy, we benefited from an in-depth (“item by item”) review by Prof. Angus Kingon (North Carolina State University). We also benefited from significant interaction with Dr. Ron Kostoff (Office of Naval Research),

search process involved application of eight search strings. These are detailed in Porter et al. (2007, Table 2a). In brief, the basic first search term “nano*” yielded about half the total. Results were augmented by additionally searching for variants on quantum, self-assembly, molecular manipulations, microscopy, and other terms (such as NEMS, quasi-crystal, or sol-gel). Results in most of those cases were further restricted to records that additionally contained terms suggestive of molecular-scale foci. We were especially concerned to limit inclusion of microscopy and biological research to activities with a molecular level orientation. The second stage involved exclusion of articles that fell outside the nanotechnology domain (e.g., nano* terms indicating water- or land-based organisms, chemical formulas such as NaNO₂ and NaNO₃) and those only referencing measurement (e.g., nanometer) without another substantive combination.

Using this approach, publication records were drawn from the Web of Science's Science Citation Index (SCI) to create datasets for the 1990–2006 (mid-year) time period. More than 406,000 publication records resulted. This dataset is more comprehensive than other analyses using the simple search term of “nano*” but lacking a full set of additional terms to pick-up nanotechnology-related research described in other ways or which focus on a narrow pre-defined set of nanotechnology journals. It is acknowledged that the use of SCI excludes many non-English language outlets, and also varies in strength by subject area (e.g., SCI is excellent for most life and physical sciences, not quite as strong in chemical, medical, and engineering research).

Results

We begin by showing a trend line based on the cumulative number of publications by country based on the location of any author/co-author's affiliate organization. We sought to use this more comprehensive locational perspective to capture the widest range

Footnote 4 continued

see especially Fig. 4 in Porter et al. 2007 that indicates quite comparable coverage with Kostoff et al. 2007. The resulting search algorithm was further tuned and validated through review by 19 researchers with nanotechnology expertise (Porter et al. 2007).

of publication activity by author country. The figure shows Germany separately, even though it is also part of the EU27, because Germany is the fourth largest producer of publications. Figure 1 shows that the EU27 comprises the largest number of publications and has since 1994. In terms of individual countries, the US is at the top followed by Japan, China, and Germany. Also pictured are three Asian Tigers—Singapore, South Korea, and Taiwan—as a bloc.

In terms of country trajectories, China's publication count shows a particularly steep slope; its cumulative publication count increased by more than 300% from 2001 to 2006. (See also Zhou and Leydesdorff 2006 for a similar finding concerning China.) The percentage shares of publications in 4 years—1991, 1996, 2001, and 2006 (estimated)—are shown in Fig. 2 to provide a further sense of country and country bloc positioning. It should be noted that there are overlaps between these country-based publication counts as co-authors from different countries are counted twice, so these percentages are not additive. In 1991, the US accounted for the highest share of nanotechnology

publications at 23%. By 1996, the EU27 comprised 26% of nanotechnology publications compared to 21% for the US. By 2006, which we are estimating based on annualizing of data from part-year 2006, China accounts for nearly 20% of the publications, just behind the US (24%) and the EU27 (31%). China's rise in nanotechnology research stands out boldly. The three Asian Tigers also demonstrate a dramatic upswing in representation, accounting for more than 10% of 2006 publications.

However, quantity alone is not sufficient to describe country position in the nanotechnology research arena. Quality and influence in the field is important to consider in depicting inter-country standing in nanotechnology (Glanzel et al. 2003). Citations, as measured by the number of times a paper has been cited, are used here to gauge the level of quality of the publications of a country. Citation counts are related to publication counts in that the greater the number of publications, the higher the probability of larger citation counts. There are exceptions to this in terms of authors with pathbreaking papers. Moreover,

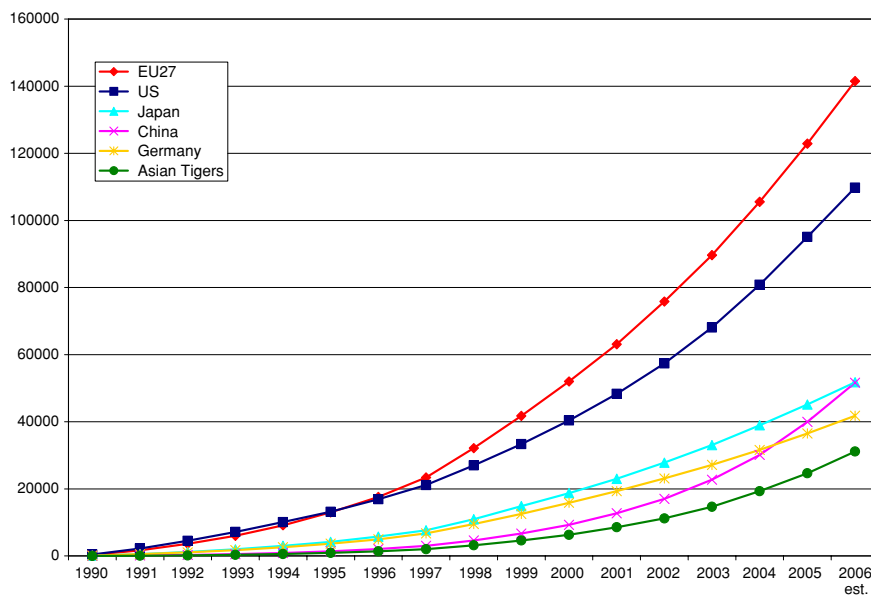


Fig. 1 Cumulative nanotechnology publications by Country/ Country Bloc*. * Nanotechnology research publications, by leading countries (USA, China, Japan, Germany) and country blocs (EU27 = European Union 27 member countries as of 2007 and Asian Tigers = South Korea, Singapore, and Taiwan), cumulative annual counts, from Web of Science, Science Citation Index (SCI), 1990–2006 (estimated). Source: Analysis by the Program in Research and Innovation Systems

Analysis, Center for Nanotechnology and Society (CNS-ASU) at the Georgia Tech Technology Policy and Assessment Center. Based on bibliometric definition of nanotechnology by Alan L. Porter, Jan Youtie, Philip Shapira and David J. Schoeneck in Refining search terms for nanotechnology, *Journal of Nanoparticle Research*, 2007 (August, Online First). Estimate for 2006 extrapolated from mid-year 2006 counts

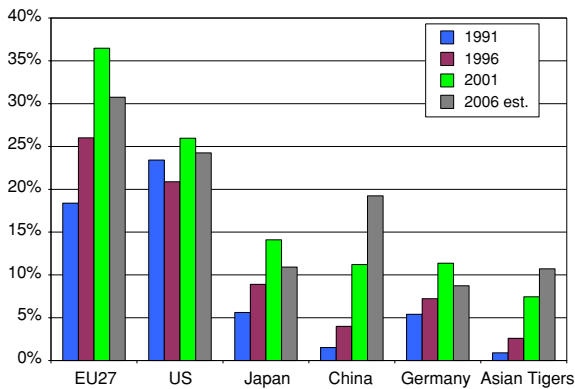


Fig. 2 Percentage of annual Nanotechnology publications by Country/Country Bloc for selected years. Source: See Fig. 1

self-citations—which are not excluded in this analysis—tend to be higher the greater the quantity of papers published by the author. The particular method used in this part of the analysis focuses on the country location of the affiliation of the first author of the publication. The first author's country is used to assign citation numbers to that country. This focus on the first author is designed to preclude duplicating citation counts. How different are the publication counts by country based on first author versus all authors? The numbers are fairly comparable as can be observed in Table 1, which

Table 1 First author versus all author nanotechnology publication counts by country

	All authors 1995	First author 1995	All authors 2005	First author 2005
<i>Counts</i>				
EU27	3,797	3,476	17,343	14,806
US	3,112	2,836	14,247	12,183
Japan	1,146	1,031	6,191	5,342
China	507	472	9,859	9,252
Germany	1,077	894	4,910	3,458
Asian Tigers	351	315	5,366	4,760
<i>Percentages</i>				
EU27	25.3%	23.2%	31.0%	26.4%
US	20.8%	18.9%	25.4%	21.8%
Japan	7.6%	6.9%	11.1%	9.5%
China	3.4%	3.1%	17.6%	16.5%
Germany	7.2%	6.0%	8.8%	6.2%
Asian Tigers	2.3%	2.1%	9.6%	8.5%

Source: See Fig. 1

compares nanotechnology publication counts based on first author's country and all authors' country in 1995 and 2005. The table shows that the country counts of nanotechnology publications based on first author's locations are slightly lower, but within range, of the country counts based on all authors' locations. Interestingly, the 2005 figures show that percentage of nanotechnology articles from the EU27 and US is much lower based on first author than on all authors, whereas these percentages are fairly close for China. This suggests that there are more collaborative authors in a secondary position on the list who are located in the EU27 and US than there are in China.

Turning to the results of the citation counts, we see that the number of nanotechnology citations is quite high for the US. In contrast to the counts of nanotechnology publications, the US has a higher number of nanotechnology citations than the EU27 (see Fig. 3). Moreover, both these countries/country blocs have much higher numbers of nanotechnology citations than do the comparator countries. Japan and Germany create a second group in terms of nanotechnology publication citations. China's citation levels do not approach those of Japan and Germany the way that their publication counts do.

One challenge is that citations are difficult to evaluate over time because earlier articles have more occasions to receive citations than do recent articles. In this article we employ a simple aging practice based on dividing the citations in a given year by the number of years of opportunity to be cited. Thus in 2000 nanotechnology citations have 5.5 years of opportunity to attract citations relative to the endpoint of our dataset, so the number of citations for that year is divided by 5.5. Similarly, in 2004 nanotechnology citations have 1.5 years of opportunity to attract citations; hence the number 2004 citations are divided by 1.5. Figure 4 shows the results relative to simple publication counts, with a line connecting the results for 2000 and 2004. The points on the left represent 2000 and the points on the right represent 2004. The steeper the slope of the line connecting these two points, the greater the quality orientation of the country/country bloc. Taking the aging effect into consideration, the US has the steepest slope, suggesting that its nanotechnology research receives the greatest attention by researchers. Likewise for Germany and Japan, although

Fig. 3 Cumulative total citations of nanotechnology publications by country: 1990 to 2006*. * The number of citations is based on the times which individual papers are cited, then combined by country. To avoid duplication, only the first author’s country is reported. This chart represents the cumulative number of citations by year for each country or country bloc shown. Source: See Fig. 1

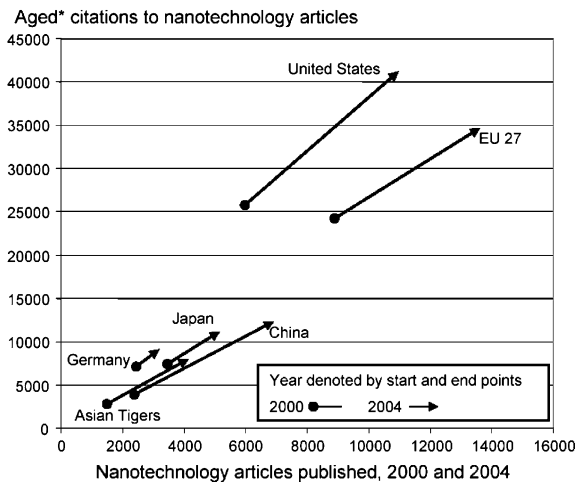
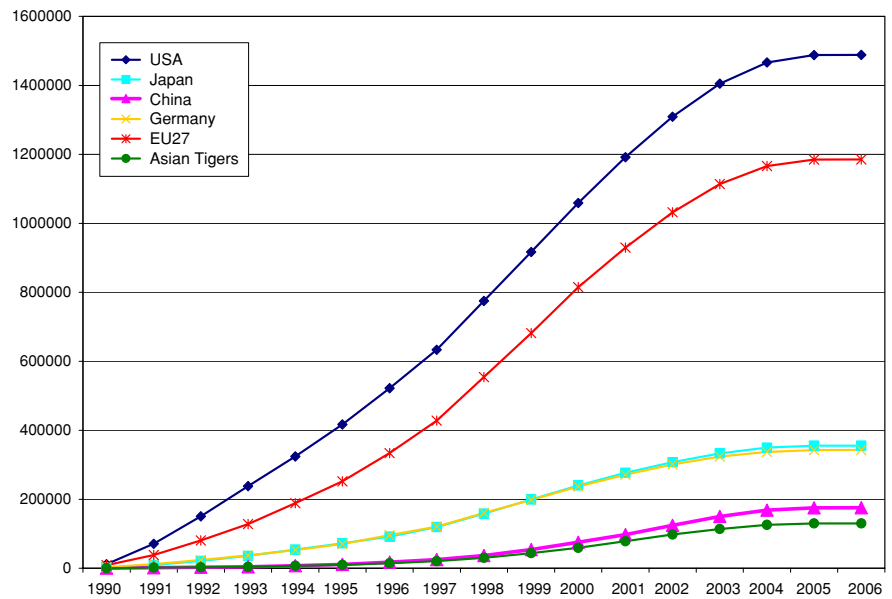


Fig. 4 Number of aged nanotechnology citations in 2000 and 2004 relative to number of nanotechnology articles by first author. * Aged citations (AC) for country_i calculated as $AC_i = C_{it}/(Y_n - Y_t)$ where C_{it} = total number of citations for articles in target year for country_i; Y_n = most recent year in dataset (2006, mid-year); and Y_t = target year. For 2000, $Y_n - Y_t = 5.5$; for 2004, $Y_n - Y_t = 1.5$. Country designated by article first author. Source: See Fig. 1

Germany and Japan have slightly fewer citations than China does in 2004, their line positioning relative to China also favors the quality axis. China’s line is the most proximate to the quantity axis, followed by that of the Asian Tigers.

Conclusions

In sum, the EU bloc and the US continue to have the largest number of nanotechnology publications as of mid-year 2006. However, their relative share of nanotechnology publications is falling. The diminishing share for the US and EU27 of course does not reflect declining absolute output of nanotechnology publications (they are continuing to grow); but in recent years, “new” Asian countries (China, Asian Tigers) have increased their publications ever more, hence taking a bigger share of the total (and pushing down the shares of nanotechnology publications from the US, EU27, and Japan). Publication counts suggest that there is more to be observed than just the numbers. For example, the differential of counts of all authors relative to those of first authors, particularly in the case of the US and EU27, suggests that these nations/blocs have greater numbers of secondary authors who are involved in network relationships with other countries. China, in contrast, has similar numbers of both types of authors, suggesting that their research does not entail as much international collaboration.

We also did not find that quality-based measures give the same perspective as do quantity-based ones. When measuring the relative positions of these countries in terms of citations, the US, in particular, demonstrates a high-quality orientation whereas China’s position seems to be more based on quantity.

A future course of investigation would involve developing enhanced methods for measuring citations at the country level. There are citation analysis issues that we could not readily address given the size of our dataset, such as self-citations and the inordinate influence of path-breaking papers with extremely high numbers of citations.⁵ Of course the SCI database used in this analysis does favor English language publications, which may dampen the measurement of China's influence in the nanoscience and nanoengineering arena.⁶ Furthermore citations can be viewed as a "lagging indicator" in the sense that past publications draw current citations. It remains to be seen whether the dominant nanotechnology citation positions of the US and EU27 relative to China (and other rising regions) are maintained in the next era of nanotechnology research.

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⁵ We experimented with the calculation of an *h*-index by country. The *h*-index is a measure that seeks to combine publication productivity and scientific impact (an index of *h* results from a researcher publishing *h* papers each with at least *h* citations, see Hirsch 2005). The results for citations in 2003 gave us *h*-index numbers as follows: US: 92; EU27: 70; Germany: 46; Japan: 44; and China: 43. This result suggests that the US retains an edge in quality of nanotechnology research despite dramatic gains of other countries in terms of quantity of research. However, the weight to be given to differences in these index figures is hard to estimate and it has not been recommended to apply the *h*-index to groups of researchers (Hirsch 2005).

⁶ Nanotechnology publication in Chinese-language journals has continued to grow in recent years, although at a significantly lower rate than for nanotechnology publication by Chinese authors in English-language journals (Lin and Zhang 2007). There are substantial incentives for Chinese researchers to publish in English-language ISI journals; field research in China in 2007 by one of the authors of this article confirms that many leading Chinese nanotechnology researchers now publish mostly in English. Additionally, as Lin and Zhang note, Chinese-language nanotechnology publication is often a bridge to communicate results available in English to exclusively Chinese-speaking researchers and is typically not at the research frontier. Hence, while we expect that using SCI does undercount China's total publication effort, available evidence suggests a relatively smaller effect on underestimating China's overall scientific quality. However, further bibliometric investigation on the quality of Chinese-language nanotechnology publication is necessary to more systematically estimate these effects.

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