# China's Quantitative Expansion Phase: Exponential Growth but Low Impact[1]

Bihui Jin* and Ronald Rousseau**

*jinbh@mail.las.ac.cn
Documentation and Information Centre of the Chinese Academy of Sciences
Chinese Science Citation Database
33 Beisihuan Xilu, Zhongguancun, Beijing, 100080 (P.R. China)

**ronald.rousseau@khbo.be
KHBO, Industrial Sciences & Technology, Zeedijk 101, B-8400 Oostende (Belgium)
& University of Antwerp, IBW, Universiteitsplein 1, B-2610 Wilrijk (Belgium)

## Abstract
It is shown that although China's publication share in the world has been increasing exponentially, its impact defined as the number of citations per publication lags far behind. This state of affairs is expressed as a 'quantitative expansion phase'. China's science needs to move from the 'quantitative expansion' phase in which it is nowadays to a 'rising quality' phase. Correspondingly scientists' motivation for publishing papers must shift from 'driven by benefit' to 'driven by excellence and timeliness'. Currently, China's science although blending into the world, is not yet a full player in its major league. Yet, all growth-related graphs show an exponential increase. Moreover, doubling times calculated in this article are clear indications that, despite obvious problems and short-comings, the quality of Chinese research as a whole is increasing very quickly. We conclude that, if the necessary measures are taken and the observed exponentially increasing trend continues, the impact of Chinese research results will soon catch up with that of other major countries.

## Introduction
A feature article bearing the intriguing title 'The scientific impact of nations' appeared in the July 15, 2004's issue of *Nature*. In it, its author, David A. King, made an analysis of the scientific impact of 31 countries including China. China is listed 28th in the so-called re-based impact list (for the year 2002 and for the period 1993-2002), a counting method that tries to avoid distortions due to different citation rates in different disciplines. Later, in another paper entitled 'The (Scientific) Wealth of Nations' which appeared in the September 27, 2004's issue of *The Scientist*, Ronald N. Kostoff presented statistics on recent papers in the highly critical field of nanotechnology. In this list China ranks first, before the USA. These two highly visible articles, both based on data provided by Thomson-ISI, reflect in one way or another the scientific impact of China, and show that scientific progress in China has attracted the attention of international policy analysts. The rapid and sustained increase in the number of Chinese articles covered by Thomson-ISI is a well known phenomenon (Huang & Wu, 2003; Jin & Rousseau, 2004; Leydesdorff & Zhou, 2005.). Does this increase follow from the combined facts that China has one of the world's largest growing economies, and that a nation's amount of produced research is strongly influenced by its wealth (Cole & Phelan, 1999)? Is China's new role in science a 'size effect', is it policy-related (i.e. the result of a special policy), or is it the quality of China's contributions to science that has brought China to the forefront in some scientific domains? This paper aims at answering these questions through a quantitative analysis of publication and citation data.

## Evolution of SCI-indexed Chinese papers

*Exponential increase of Chinese articles in the SCI*
It is well-known that the number of SCI-indexed Chinese papers (SCI-CPs in short) is rising rapidly. A Chinese article is defined here as an article where at least one of the authors has a Chinese address. We collected numerical information on SCI-CPs (including Hong Kong) for the period 1991 - 2003 and plotted them in Figs. 1 and 2 (see also Appendix). Fig. 1 shows the trend in absolute numbers of

[1] The authors thank Zhang Wang and Sun Hairong for collecting and standardizing the data. Work for this article was supported by a Major State Basic Research Special Program of China under grant No.2003CCC00100.

*Proceedings of ISSI 2005, pages 362–370.*
*Edited by P. Ingwersen and B. Larsen.*

SCI-CPs while fig. 2 depicts the evolution of the proportion of SCI-CPs in the world total. Dashed lines in these figures represent best fitting exponential regression curves. Clearly, these regression lines fit almost perfectly, showing that both trends are indeed exponential. For the absolute growth (Fig.1) the regression function is: $y = 7191*\exp(0.147*t)$, $t = 1, \ldots 13$ where the year 1991 corresponds to $t = 1$ (with $R^2 = 0.996$). The function $y = 1.006*\exp(0.116*t)$ gives a best fitting exponential growth curve for proportional growth (Fig.2), with $R^2 = 0.991$. The growth rate for the first curve is 0.147, a doubling time of 4.7 years, while the growth rate for the second one is 0.116 (a doubling time of 5.98 years). This difference indicates that the ISI publication database itself is growing, which is a correct observation (see Appendix).

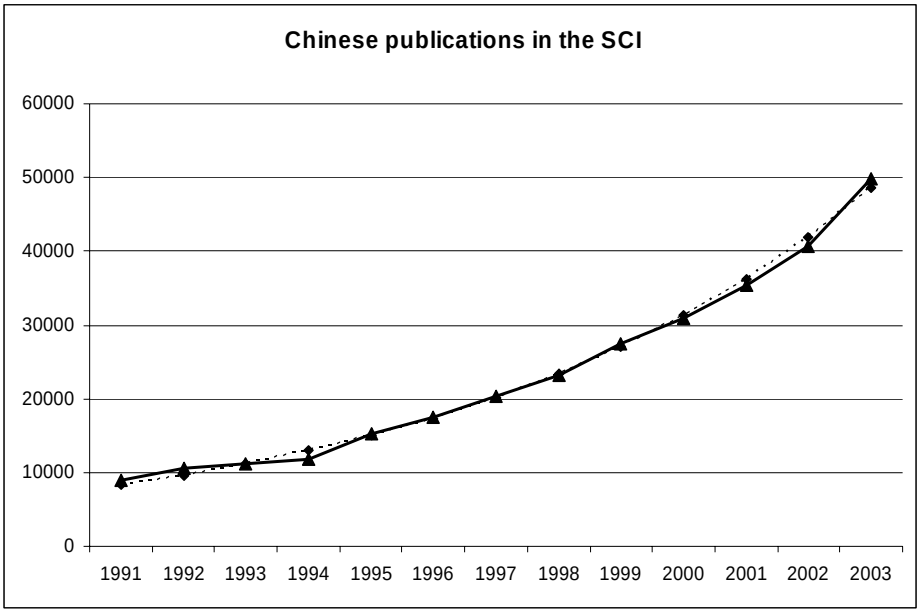


Fig.1: Absolute growth (full line) and best fitting exponential curve (dotted line)

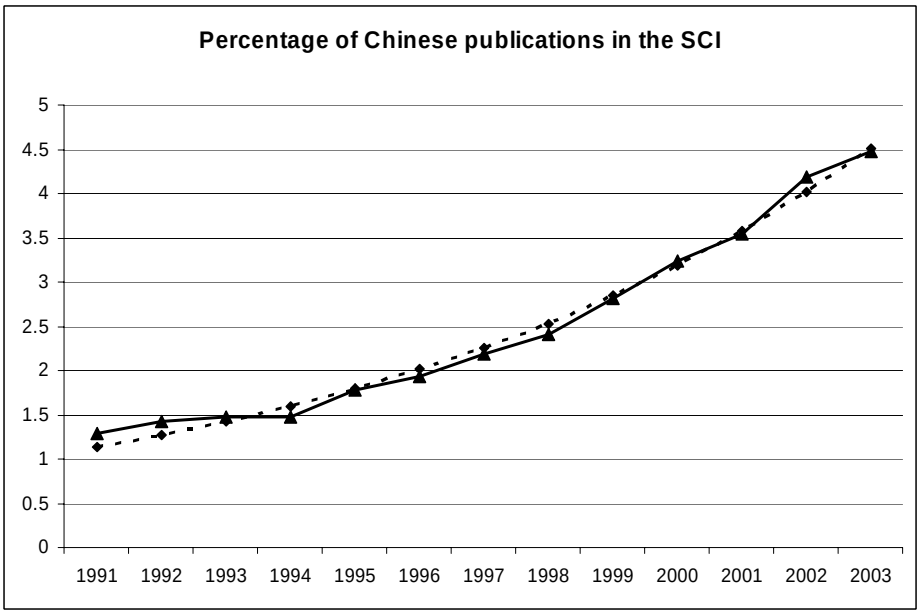


Fig 2: Relative growth (full line) and best fitting exponential curve (dotted line)

The extraordinary, even spectacular, rise in the number of Chinese papers has been attracting the attention of scientists and policy analysts from all over the world (Leydesdorff & Zhou, 2005). A question lingering in people's mind is why this number is rising at such a high speed. We contend that this phenomenon has a policy-related background. In the past ten years, universities and research

institutes in China adopted the SCI as the main indicator for research evaluation, and simply equate SCI-CPs with high quality papers. Subsequently, a competition in the number of SCI papers started across all organizations. Moreover, various incentive measures were taken, one of which is to give special rewards to SCI papers: the more papers indexed by Thomson-ISI are published, the higher the reward for the institute or research group, sometimes even for the researcher herself. The immediate result of this policy was that the energy of Chinese scientists became focused towards publication in ISI-covered international journals. In fact, this policy of linking the number of SCI papers to one's personal financial interests might be considered the main factor of the increase of Chinese SCI papers. Large financial investments, fuelled the exponential growth of Chinese scientific publications, pushing China into a state of 'quantitative expansion'.

*Distribution of Chinese papers in domestic and international journals*

Academic exchange in China can be divided according to the language used into an international circle and a domestic one. The former refers to Chinese scientists publishing in international journals, and thus participating in scientific exchange with their peers on a world basis. The latter refers to publications in Chinese journals, especially those journals publishing exclusively in Chinese language. In this case knowledge exchange occurs predominantly with colleagues within the country. Unfortunately, Chinese journals publishing articles exclusively in English play only a minor role in the scientific publication system (Ren & Rousseau, 2004).

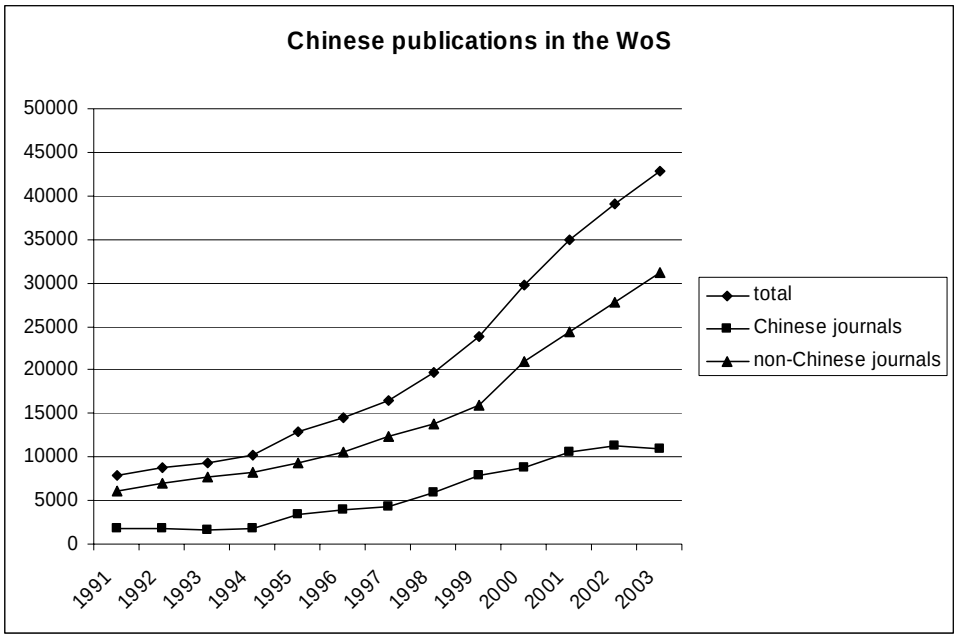


Fig.3: Chinese publications in the Web of Science

The increase in the number of SCI-CPs is accompanied by a rapid increase in the number of SCI-indexed Chinese journals. From the beginning of the 1990s to 2003, this number increased from 12 journal titles to 71. These journals predominantly publish in English. Is then the increase of Chinese journals the main factor in the increase in papers? This is not the case. Our statistics show that only 26% of the total number of SCI-indexed Chinese articles appeared in Chinese journals. Fig. 3 shows that in the period of 1991 - 2003 the number of papers published in Chinese journals as well as that in non-Chinese journals have been rising. Yet, papers published in non-Chinese journals were dominant. Expressed as a percentage share, however, the increase in the number of Chinese journals covered by ISI is clearly visible (Fig.4). In recent years this share lies between one quarter and one third. In addition, in the year 2000 non-Chinese journals were the source of almost 90% of all citations received by Chinese articles. We therefore conclude that papers published in non-Chinese journals play a dominant role in the increase in the number of SCI-CPs. These articles also play a pivotal role in helping raise the international visibility of China.

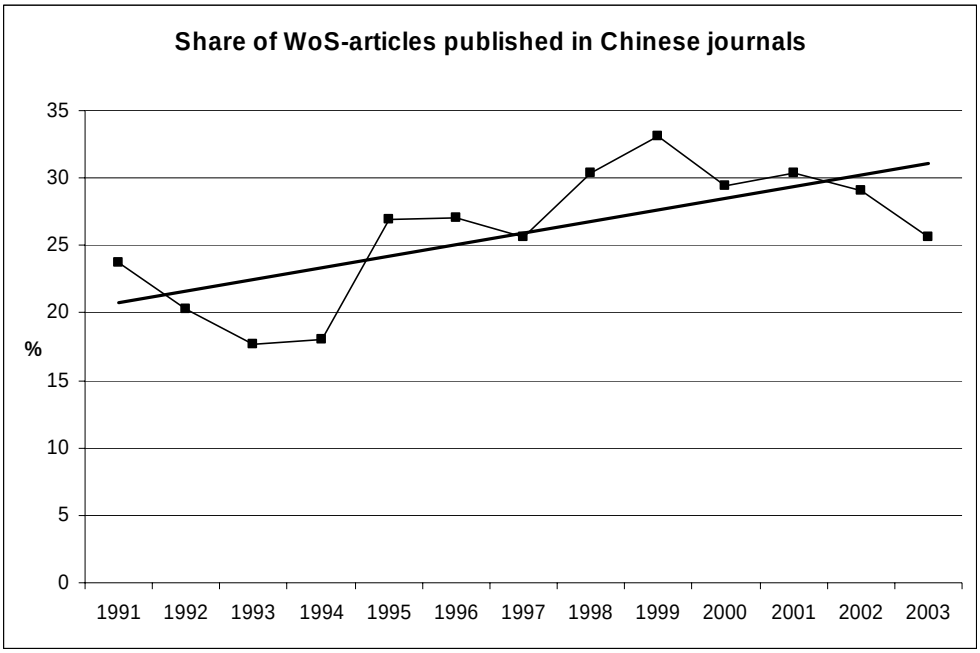


Fig. 4: Share of Chinese articles included in the Web of Science and published in Chinese journals and linear regression line

We note that in the discussions in this section and the following ones only publications of the following types are included: articles, discussions, hardware reviews, letters, notes, reviews and software reviews. This explains the different totals with respect to the first section of this article.

*Internationally co-authored papers*

Research collaboration is a well known strategy for narrowing the gap between a country and scientifically more advanced nations. Since China's opening to the outside world the collaboration of Chinese scientists with their counterparts in the world has steadily been increasing. In 1991, the number of papers co-authored by Chinese scientists and scientists from other countries was only 1,858. This number reached 10,200 in 2003, a phenomenal increase by more than 500% (Fig. 5). That year internationally co-authored articles account for 24% of the year's total. This curve too can be fitted by an increasing exponential function: $y = 1256*\exp(0.165*t)$, $t = 1, \ldots 13$ where the year 1991 is $t = 1$ (with $R^2 = 0.984$). Note that the growth rate for internationally collaborated articles is higher than that for all publications. Equivalently, its doubling time, namely 4.2 years, is smaller than that of all publications.

Over the period 1998 - 2003, scientists from 132 countries and regions collaborated with Chinese scientists. America, Japan, Germany, UK and Australia are the top five countries on this list. These internationally collaborated articles are predominantly published in international journals. Yet the percentage of such articles published in Chinese journals also increased: from less than 2% in the period 1991 – 1995 to more than 4% in the latest period. This increase is probably the result of the increase in coverage of Chinese journals by ISI. In addition, we note that the five-year total of co-authored papers in 1999 - 2003 is 2.5 times that of 1994 - 1998. All this demonstrates that China's science is blending into the world's science at an ever faster pace. Leydesdorff and Zhou (2005) even put that China and neighbouring Asian countries are shifting the balance of the world system of science.

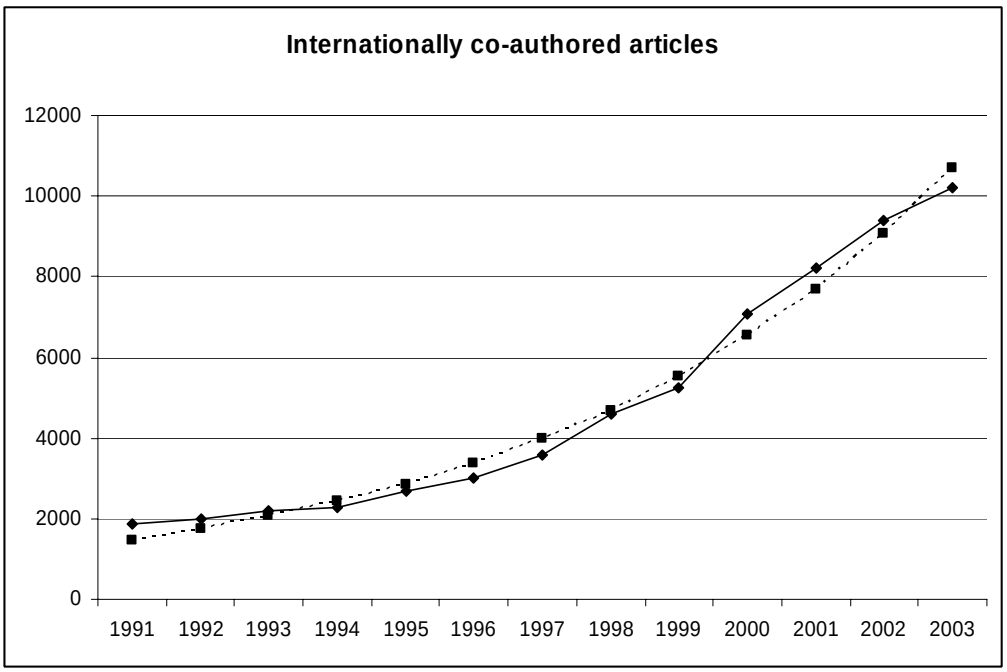


Fig.5: Number of internationally co-authored Chinese articles included in the WoS: another exponentially increasing curve

**China's position in ISI's Essential Science Indicators (ESI)**

Science is an intrinsic aspect of the ascent of man (Bronowski, 1973). Progress in science emerges from man's efforts to tackle unsolved problems and the exploration of the laws of nature. Its ultimate goal should be to serve mankind. Research publications (articles, books, reports, etc.) available in electronic form or on paper, large or small, all are carriers of research results or reflections on them. Publications making a real contribution to the progress of science will attract other scientists' attention. These colleagues will pursue previous investigations and delve deeper into subjects and problems introduced by their peers. One method of studying this network of influences is through citation relations (Garfield, 1979, 2004; Hargens, 2000).

The number of papers published during a specific period is a simple, basic metric for the output of scientific research during that period. More importantly, the number of received citations is related to the visibility of research groups at the research front (Russell & Rousseau, 2002). According to data from ISI's Essential Science Indicators (ESI) (November 2004) China ranked 9$^{th}$ in the world according to the number of published papers over the period January 1994 to August 2004. It ranked 18$^{th}$ according to the number of received citations. Yet, for the number of citations per paper China ranks only 124$^{th}$. Such a drastic contrast between these three indexes tells us again that China's science is only in a 'quantitative expansion' phase. When science is in a healthy state, an increase in the number of papers is not only accompanied by an increase in the number of total citations, but also by an increase in the number of citations per paper. This is not the case at all for China. In order to analyze the scientific impact of China in the world we now have a closer look at the citation data.

*China and the most-cited articles in the ESI database*

We use data from Thomson-ISI's Essential Science Indictors (ESI) for further analysis. Articles belonging to the set of most cited 10% over the period 1994-2003 will be the main source of attention. One may argue that the impact of a country's scientific research corresponds to the proportion of highly-cited papers of that country: the higher this proportion, the greater a country's scientific impact in the world. Yet, a cautionary note should be added here (Leydesdorff & Zhou, 2005). Citation rates differ among fields of science, and even among specialties within these fields. As such countries focusing on the life sciences are at the advantage with respect to countries focusing on engineering

sciences or mathematics. Our article only studies Chinese science as a whole, and does not take developments in different fields into account.

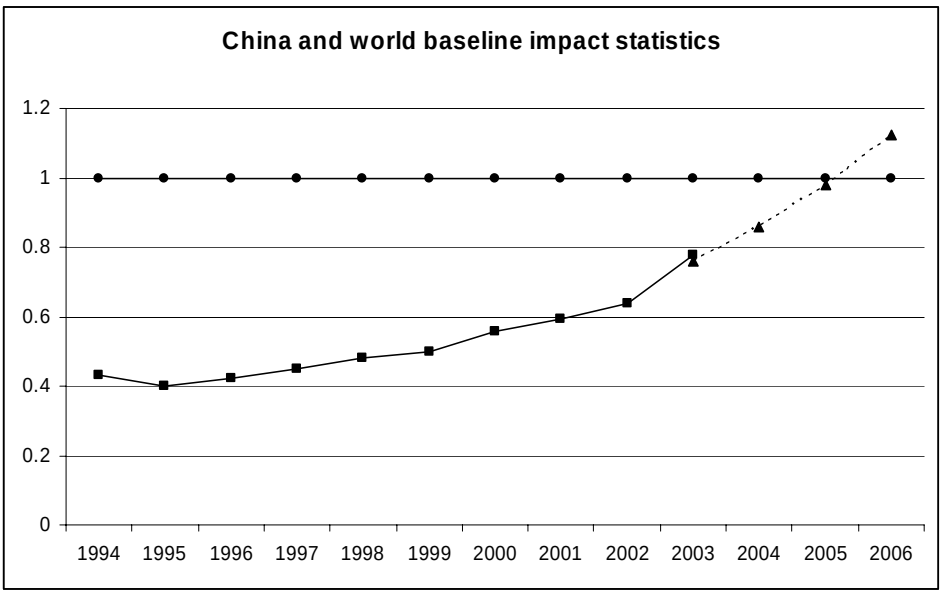


Fig.6: China's articles approach the world average number of citations

We found that the number of citations per paper for Chinese papers is lower than that of the world. China accounts for a relatively small fraction of articles belonging to this most-cited 10% group (taken over all fields). When considering the average number of citations received by an article published in the year Y over the period [Y, 2003] as a baseline, we see (Fig.6) that the average number of citations received by Chinese articles in approaching this baseline. This graph shows that China is really making progress: the visibility of its scientific articles is increasing over the years. If this trend continues (dotted line) then China will reach world average by the end of the year 2005.

Another indicator provided by the ESI database is the least number of citations, for each publication year, in order to belong to the x% most-cited ones. Here x = 0.01, 0.1, 1 and 10. Table 1 illustrates this for the year 1996. At least 31 citations over the period [1996, 2003] are necessary in order to belong to the 10% most-cited articles of that year. Recall that only articles published in SCI-covered journals are taken into account here.

Table 1. World baselines for the year 1996, period [1996, 2003] (data from the ESI)

| Baseline | 0.01% | 0.1% | 1% | 10% |
|---|---|---|---|---|
| Minimum number of citations required | 1037 | 372 | 123 | 31 |

The number of Chinese articles reaching this 10% baseline is also increasing exponentially: $y = 143.4 * \exp(0.295*t)$, $t = 1, \ldots 10$ where the year 1994 is $t = 1$ (with $R^2 = 0.995$). The doubling time for this exponential curve is 2.35 years. Clearly, for this indicator too China is quickly catching up with the rest of the world.

*Highly cited papers: internationally co-authored papers and papers written by Chinese authors only*
In a previous section we showed that the in China the number of internationally co-authored papers in 2003 is 5.5 times higher than in 1991. This observation refers to the quantity of international collaboration. Now we study the visibility aspect. Are these internationally co-authored papers cited more than those exclusively written by Chinese scientists? In order to clarify this issue we collected data on these two types of papers meeting the top 10% citation baseline. In this selective group we notice that the percentage of articles written exclusively by Chinese authors is increasing (Fig. 7). This is a surprising result. It shows that although collaboration with foreign colleagues is increasing the quality (as measured by citation counts) of pure Chinese contributions is increasing too.

*Which countries cite China the most, or which countries are following China's scientific investigations with the greatest interest?*

Which countries are most interested in scientific results published in Chinese articles? In order to answer this question we consider the Chinese articles belonging to the top 10% most-cited ones for the period 1999-2001. This is a set of 3,433 articles. These articles are cited 80,479 times between the moment they were published and August 2004. These citations originated for about 70% from non-Chinese articles, i.e. articles with no Chinese address. Note that more and more Chinese scientists work abroad and hence have a non-Chinese address. In our analysis these authors are included in the group of non-Chinese authors.

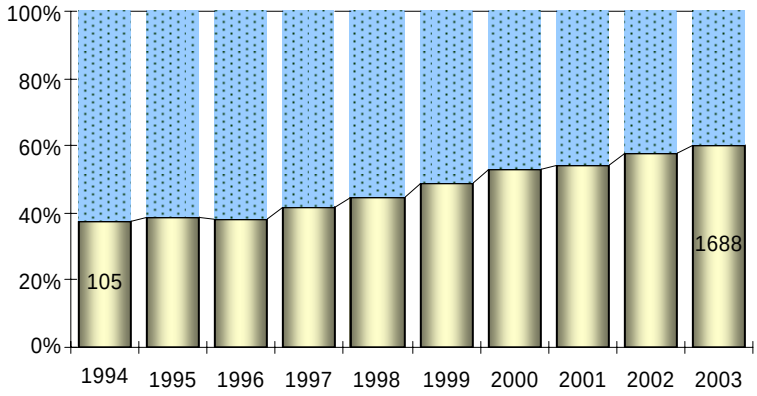


Fig. 7: Percentages and absolute numbers of exclusively Chinese (lower part) versus internationally collaborated articles (upper part) among the 10% most-cited in the world (according to ESI data)

These 'foreign' citations came from 147 different countries. Leading countries citing top Chinese articles are: USA, Japan, Germany, UK, France, Italy, Canada, South Korea and Spain. Table 2 gives detailed information, including citations in Chinese articles. This table shows that in 1999 Chinese papers did not receive much citation response from eight of the ten countries. Only the USA and China itself contributed a three-digit citation number. However, from the year 2000 on, also the other eight countries began to show a three-digit number of citations, and by 2003, the five scientific powers, USA, Japan, Germany, UK, and France, even show a four-digit number of citations.

Table 2. Citations of Chinese articles per country and per year

| **Nation** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **Total** |
|---|---|---|---|---|---|---|---|
| USA | 292 | 1640 | 3921 | 6280 | 6982 | 5273 | 24388 |
| P R CHINA | 271 | 1515 | 3686 | 5607 | 7001 | 6154 | 24252 |
| JAPAN | 70 | 420 | 1018 | 1809 | 2197 | 1641 | 7156 |
| GERMANY | 57 | 398 | 1039 | 1650 | 1792 | 1419 | 6355 |
| ENGLAND | 53 | 374 | 907 | 1367 | 1464 | 1129 | 5295 |
| FRANCE | 39 | 283 | 692 | 1134 | 1221 | 956 | 4326 |
| ITALY | 40 | 237 | 467 | 857 | 940 | 752 | 3293 |
| CANADA | 31 | 176 | 456 | 748 | 833 | 668 | 2912 |
| SOUTH KOREA | 2 | 105 | 289 | 580 | 738 | 681 | 2395 |
| SPAIN | 15 | 125 | 293 | 544 | 673 | 549 | 2199 |

One should, however, not forget that only a small fraction of Chinese papers gains international attention. The 3,433 papers meeting the top 10% citation baseline in 1999 - 2000 only account for less than 4% of the total. This means that many Chinese authors get published, but relatively few get noticed. Besides absolute numbers one may also consider relative numbers. Then one finds that

Taiwan includes citations to Mainland China in more than 12% of its papers (all papers, not just the most-cited ones). Further also South Korea (almost 10%), Singapore (almost 3%) and Australia (1.5%) have a larger percentage of articles in which they cite China than the United States (1.2%) (these data refer to publications in 1999 and 2000, and their citations up to October 2004.)

## Conclusions

*A. Model-theoretic observations*

We have shown that the absolute growth curve as well as the relative growth curve (relative with respect to the SCI database) of Chinese publications are exponential functions. Further, both the number of internationally co-authored Chinese articles, and the number of Chinese articles reaching the 10% baseline are exponential curves.

For the absolute growth in publications covered by the SCI the doubling time is 4.7 years; for the proportion of Chinese articles in the database it is 5.98 years. The doubling time for internationally co-authored articles is 4.2 years, while for the number of Chinese articles that belong to the group of 10% most-cited it is 2.35 years.

All these numbers illustrate Price's exponential model (Price, 1963). Of course, one does not expect that such an exponential growth would be sustainable over prolonged periods.

*B. Policy-related conclusions*

Chinese universities and research institutes have adopted a number of policies, aiming at encouraging scientists to publish in SCI-indexed journals. This has led to a 'concentration effect' of Chinese papers in SCI-indexed journals. Clearly, the exponential increase in SCI-CPs since 1991 has a policy-related background. However, the obvious imbalance between the number of papers and the corresponding impact shows that China's science is only at a 'quantitative expansion' phase. As a peripheral country, international collaboration is playing an important role in the scientific development of China. In 2003, nearly one out of every four papers was co-authored by foreign authors. This is a result of the increase in international exchange between China and the other countries of the world.

International scientific communities are paying closer attention to the scientific developments in China. Nevertheless, among the total number of Chinese papers, only a small portion has attracted the attention of the international community. Data on the distribution of citations of Chinese papers show that about 80% of the papers fall in the region with very low or even zero citations, a fact deserving attention by both scientists and policy-makers in China. The situation as shown in this contribution should be a warning sign for Chinese policy-makers. Measures for improving the quality of China's scientific results should be taken immediately. Scientific leaders must encourage the pursuit of new discoveries and the advancement of science. Just getting published should not satisfy scientists, and institutional and academic managers.

*C. Final conclusions*

In 1935 Lin Yutang wrote "China has been backward in natural science. I have confidence, however, that with the importation of the scientific method, and with adequate research facilities, China will be able to produce great scientists and make important contributions to the scientific world in the next century." (Lin, 2000, p.78). Although China still has a long way to go, it seems that this prediction, made 60 years ago, is coming true.

China's science needs to move from the 'quantitative expansion' phase in which it is nowadays to a 'rising quality' phase. Correspondingly, scientists' motivation for publishing papers must shift from 'driven by benefit' to 'driven by excellence and timeliness'. Currently, China's science although blending into the world, is not yet a full player in its major league. Yet, all growth-related graphics show an exponential increase. Moreover, the doubling times mentioned above are clear indications that, despite obvious problems and short-comings, the quality of Chinese research as a whole is increasing very fast. Indeed the doubling time for belonging to the group of most-cited articles is shorter than that for internationally co-authored articles, which in turn is shorter than that for the number of articles in the SCI. We may conclude that, if the necessary measures are taken (and this is

an essential prerequisite) and this exponentially increasing trend continues, the impact of Chinese research results will soon catch up with that of other countries.

## References


Bronowski, J. (1973). *The ascent of man*. London: British Broadcasting Corporation.

Cole, S. & Phelan, T.J. (1999). The scientific productivity of nations. *Minerva*, 37, 1-23.

Garfield, E. (1979). *Citation indexing: its theory and application in science, technology, and humanities*. New York: Wiley.

Garfield, E. (2004). Historiographic mapping of knowledge domains literature. *Journal of Information Science*, 30, 119-145.

Hargens, L.L. (2000). Using the literature: reference networks, reference contexts, and the social structure of scholarship. *American Sociological Review,* 65, 846-865.

Huang, N. & Wu, Y. (2003). A comparative study of scientific and technical output indicators of Mainland China and Taiwan region. *Current Science*, 84, 634-639.

Jin, B. & Rousseau, R. (2004). Evaluation of research performance and scientometric indicators in China . In: *Handbook of quantitative science and technology research. The use of publication and patent statistics in studies of S&T systems*. Editors: Henk F. Moed, Wolfgang Glänzel , Ulrich Schmook. Kluwer Academic Publishers, Dordrecht, 2004, Chapter 22, 497-514

King, D.A. (2004). The scientific impact of nations. *Nature*, 430, 311-316.

Kostoff, R.N. (2004). The (scientific) wealth of nations. *The Scientist*, 18(18), p.10.

Leydesdorff, L. & Zhou, P. (2005). Are the contributions of China and Korea upsetting the world system of science? *Scientometrics* (to appear).

Lin, Y. (2000). *My country and my people*. Foreign Language Teaching and Research Press, Beijing (reprinted version).

Price, D.J. de Solla (1963). *Little science, big science*. New York: Columbia University Press.

Ren, S. & Rousseau, R. (2004). The role of China's English-language scientific journals in scientific communication. *Learned Publishing*. 17, 99-104

Russell, J.M. &. Rousseau, R. (2002). Bibliometrics and institutional evaluation. In : *Encyclopedia of Life Support Systems (EOLSS)*. Part 19.3 Science and Technology Policy, edited by Rigas Arvantis. Developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK.

Thomson-ISI. *Essential Science Indicators* (ESI)


## Appendix

Table 4 Number of articles in the SCI database and number of Chinese articles

| Year | # articles in SCI | # Chinese + Hong Kong articles | Year | # articles in SCI | # Chinese + Hong Kong articles |
|---|---|---|---|---|---|
| 1991 | 695688 | 8997 | 1998 | 960258 | 23093 |
| 1992 | 741536 | 10502 | 1999 | 974253 | 27489 |
| 1993 | 754305 | 11085 | 2000 | 956533 | 30917 |
| 1994 | 798221 | 11819 | 2001 | 999749 | 35461 |
| 1995 | 855262 | 15245 | 2002 | 974850 | 40750 |
| 1996 | 904198 | 17480 | 2003 | 1111386 | 49788 |
| 1997 | 927786 | 20305 | | | |

Somewhat surprisingly also for the total number of articles in the SCI an exponential curve can be fitted. Its equation is: $y = 708{,}207*\exp(0.0326*t)$, $t = 1, \ldots 13$ ($R^2 = 0.904$). The doubling time is 21 years, which is much larger than the corresponding value for China's contributions. Note though that the function $y = 589{,}893 + 97{,}345\ t^{0.611}$ , $t = 1, \ldots 13$, gives a better fit ($R^2 = 0.929$).