Highly cited papers from India and China

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Research papers published by Chinese and Indian researchers during 1998–2007 and cited at least 100 times by end of 2009 are analysed. There were 776 papers with at least one author from India (amounting to 0.32% of all papers from India) and 2260 papers with at least one author from China (0.4% of all papers from China) that have gone on to be cited at least 100 times. We have identified prominent authors and institutions, journals used and fields of research. Although highly cited Chinese papers were cited on average less often than the highly cited papers from India, Chinese authors have been able to place their papers in high impact journals such as Nature and Science far more often than Indian authors. The Indian Institute of Science, Bangalore, Tata Institute of Fundamental Research, Mumbai and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore are the prominent Indian institutions, whereas universities in Hong Kong, Peking University, Tshing Hua University and several institutions under the Chinese Academy of Science dominate in China. In terms of citations, Chinese National Human Genome Centre Shanghai, Shanghai, tops the list.

Keywords: Citations, impact factor, research papers, science and technology.

THE geography of science is changing. Science and engineering research is becoming an increasingly international endeavour. More than ever before governments around the world acknowledge the role of science and technology (S&T) in generating new jobs, economic prosperity, response to national issues and global challenges, and global competitiveness[1].

China and India are seen as emerging world leaders and there has been considerable interest in what happens in the area of S&T in these two countries. A few years ago, Demos, the London-based think tank, brought out a series of reports on the theme *Atlas of Science: Mapping the Geography of Science*. Two of them were on science in China and India[2,3], and the third was on South Korea[4]. Together with Brazil and Russia the two Asian giants constitute the BRIC countries and together with Brazil and South Africa they constitute the BASIC countries. Thomson Reuters, the publishers of *Web of Science* and related databases, have brought out a series of studies on science in the BRIC countries[5–10]. In his State of the Nation address delivered on 27 January 2010, the US President Barak Obama made a mention of both China and India as countries trying hard to excel and he made a special reference to their emphasis on mathematics and science (education and research)[11].

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Ronald Kostoff and his colleagues have estimated the quantity, scope and quality of scientific research in both China and India[12,13]. According to Kostoff, from 1980 to 2005, India's output of research articles grew by a factor of 2.5, from 10,000 to 25,000, and that during the same period, Chinese research output grew by a factor of 100. Today, in the output of research papers as seen from *Web of Science*, China is second only to USA. However, Kostoff reports that if we look at *INSPEC* and *Compendex*, China has outpaced USA as well. This is because *Web of Science* covers a large number of biomedical and life sciences journals and China's strong suites are physics, chemistry, materials science and engineering.

Shelton and Foland believe that although currently China lags behind USA and the European Union in most S&T indicators (except the sheer output of research papers), it will soon catch up and possibly excel USA and Europe[14]. It is not China alone that is expected to upset the current order in world science, and even displace USA from its position as the world's number one, according to Leydesdorff and Wagner[15]. According to Leydesdorff and Zhou[16], China and South Korea are improving both in terms of the sheer volume of research publications and citation impact.

A recent announcement from *Nature* Asia-Pacific provides additional evidence, if any required, for China's phenomenal growth in science. From a mere three papers published by Chinese researchers in *Nature* and other monthly journals from the *Nature* Group in 1998, the number rose to 93 in 2009. In contrast, India had published two papers in 1998 and 18 in 2009. Over the

12 years China had published 375 papers compared to 63 from India (http://www.natureasia.com/en/publishing-index/historical.php?).

Arunachalam[17] had shown that many papers published by Indian researchers in high impact factor journals are cited much less often than the average article in those journals and thus actually bring down the impact factor of those journals. Balaram[18] pointed out that 'journal impact factors can be misleading with most papers in high profile journals accumulating only a modest number of citations'. Recently, Meneghini *et al.*[19] have shown that papers from Latin America published in high impact factor journals are cited on average less often than the journal average. Campbell[20] has shown how a high journal impact factor can be the skewed result of many citations of a few papers rather than the average level of the majority, reducing its value as an objective measure of an individual paper. A better measure of an individual paper would be the actual number of times the paper is cited. In this article, we have estimated the number of papers from India and China published in 10 years, 1998–2007, that have been cited at least a hundred times.

Here again, one has to be aware that the average number of citations to papers differs from field to field, and in certain areas the normal citation rates are rather low. As pointed out by Pudovkin and Garfield[21,22], average impact factor values greatly differ among subject categories and an average paper in mathematics is cited eight times less frequently than an average paper in molecular biology or genetics. *Essential Science Indicators*[23] provide information on average number of citations per paper for 22 major fields. Obviously there would not be many mathematics papers from India or China that would have been cited hundred times or more.

Methodology

With a view to finding the highly cited papers from India and China, the authors of these papers as well as the institutions where they were written, we downloaded all papers published in 1998–2007 with an author address in India and China from *Science Citation Index – Expanded* section of *Web of Science*. We selected papers that have been cited at least 100 times up to a given date. These data were then analysed using Visual FoxPro.

Analysis of data

In Table 1, we present the number of papers published by Indian and Chinese researchers in all of science as seen from *Web of Science* in each one of the years 1998–2007. We have also shown the number of papers from these two countries that have been cited at least 100 times. To see the performance of India and China in perspective we have included similar data from two other BASIC countries, viz. Brazil and South Africa; three OECD countries, viz. France, Japan and South Korea, and Israel, a small country with a good record in scientific research. Citation data were collected up to 22 November 2009 for India, China, South Korea and Brazil and up to 25 January 2010 for Israel, South Africa, Japan and France.

In all, India had published 235,679 papers in the 10 years, and of these 758 were cited at least 100 times. China had published 529,856 papers during the same period, and of these 2,142 were cited at least 100 times. Among the eight countries considered, India and China have the lowest proportion of papers receiving 100 citations, viz. 0.321% and 0.404% respectively. In contrast, Israel (1.737%), France (1.585%) and Japan (1.071%) have a much higher proportion of papers receiving at least 100 citations. South Africa (0.790%), South Korea (0.501%) and Brazil (0.419%) have recorded a slightly higher proportion of papers receiving at least 100 citations than India and China. Israel's performance, better than that of the three OECD countries (France, Japan and South Korea) is striking.

In Table 2, we present data on the number of papers from India and China, the number of papers with more

Table 1. Comparison of number of papers published during 1998–2007 and number of highly cited papers from India, China, South Korea, Brazil, Israel, South Africa, Japan and France

	India*		China*		South Korea*		Brazil*		Israel**		South Africa**		Japan**		France**	
Year	Papers	A	Papers	A	Papers	A	Papers	A	Papers	A	Papers	A	Papers	A	Papers	A
1998	17,629	101	20,621	165	11,822	96	10,277	92	10,025	339	4047	52	77,678	1551	53,989	1558
1999	18,073	92	24,639	190	13,683	134	11,732	93	10,364	307	4239	55	79,541	1545	54,790	1459
2000	18,137	109	31,028	255	15,116	165	12,978	83	10,688	294	3998	50	82,217	1432	54,753	1430
2001	19,141	113	36,505	267	17,505	160	13,736	83	10,576	274	4194	47	81,053	1311	53,948	1253
2002	20,656	90	41,354	336	19,371	156	15,888	92	11,336	231	4428	28	85,272	1099	55,383	1071
2003	22,846	91	50,954	314	22,729	137	16,749	81	11,748	201	4388	30	89,081	841	56,579	849
2004	24,783	67	61,432	264	27,025	118	18,362	65	12,229	143	4704	47	90,278	655	59,322	686
2005	27,482	51	74,257	229	29,392	80	19,465	65	12,323	111	5041	28	89,343	411	67,517	513
2006	30,979	34	90,737	81	32,342	45	21,911	34	12,640	69	5687	25	92,928	236	64,769	308
2007	35,953	10	98,329	41	33,570	23	27,661	19	12,555	20	6510	11	89,766	100	66,043	177
Total	235,679	758	529,856	2142	222,555	1114	168,759	707	114,484	1989	47,236	373	857,157	9181	587,093	9304

A, Number of papers receiving at least 100 citations; *Data collected on 22 November 2009; **Data collected on 25 January 2010.

Table 2. Number of papers and papers with 100 or more citations from India and China published during 1998–2007

	India*			China**		
Year	No. of papers	Papers with ≥100 citations	Sum of citations	No. of papers	Papers with ≥100 citations	Sum of citations
1998	17,629	104	22,953	20,621	170	30,414
1999	18,073	92	17,198	24,639	193	35,273
2000	18,137	111	21,757	31,028	261	43,930
2001	19,141	115	19,230	36,505	277	54,161
2002	20,656	92	20,336	41,354	344	61,129
2003	22,846	93	19,198	50,954	343	61,002
2004	24,783	69	15,753	61,432	282	46,834
2005	27,482	52	9544	74,257	246	44,444
2006	30,979	37	8450	90,737	94	17,423
2007	35,953	11	1378	98,329	50	8,602
Total	235,679[+]	776	155,797	529,856[†]	2260	403,212

*Data collected on 12 December 2009; **Data collected on 12 January 2010; [†]0.321% of Indian papers and 0.404% of Chinese papers have been cited at least 100 times.

than 100 citations and the sum of citations received by these highly cited papers. Overall, the 776 Indian papers that have been cited at least 100 times have accumulated 155,797 citations for an average of 200.8 cites per paper, and the 2,260 Chinese papers with at least 100 citations have been cited 403,212 times for an average of 178.4 cites per paper. When looked at from another angle, 70 of India's 776 highly cited papers (9%) are cited more than 300 times, compared to 173 of the 2,260 highly cited Chinese papers (7.65%). As expected, papers published in recent years are cited less often than those published in earlier years.

More than 29% of the 776 highly cited Indian papers are review articles, compared to 10% for China. These have received about 227 and 230 cites per paper respectively. The 519 original research papers from India have received on average 192 cites per paper and the 1,943 original research papers from China have received 173 cites per paper.

Papers in high impact journals

Often science administrators and policy makers look at the number of papers published in influential journals when evaluating individuals and institutions. Table 3 lists more than 30 journals in which Indian and Chinese researchers have published their highly cited papers. China has published a far higher proportion of highly cited papers in high impact journals such as *Nature* (impact factor 28.75), *Nature Medicine* (26.38), *Science* (26.37), *New England Journal of Medicine* (52.59), *Journal of the American Medical Association* (*JAMA*) (25.55) and *Lancet* (28.64) than India. Use of journals in different impact factor ranges by Indian and Chinese scientists to publish their highly cited papers is shown in Table 4. Indian researchers have used 317 journals in all to publish 776 highly cited papers that have received a sum of 155,797 citations. Of these, 165 papers have appeared in journals of impact factor (*JCR* 2007) higher than 10.0, and these have received 38,648 citations. Chinese researchers have used 557 journals to publish 2,260 highly cited papers and these have received 403,212 citations. Of these 510 papers were published in 50 journals of impact factor higher than 10, and these have received 129,506 citations. Of the 27,973 papers published in *Nature* in 10 years, only 220 have come from China and only 115 have come from India. Of the 26,768 papers published in *Science* in 10 years, 310 have come from China and 101 from India. Chinese researchers have published 50 highly cited papers in *Lancet* compared to 13 by Indian researchers. In *New England Journal of Medicine*, Chinese and Indian researchers have published respectively 32 and 5 papers. In *Nature Genetics* (impact factor 25.56), China has 17 highly cited papers against four from India. In *Nature Medicine* (impact factor 26.38), China has published 13 highly cited papers against one from India. In *JAMA* (impact factor 25.55), Chinese researchers have published 10 highly cited papers as against three by Indian researchers.

The 220 papers from China in *Nature* have accumulated 34,167 citations for an average of 155.3 citations per paper. Of these 220 papers, only 43 were written by Chinese authors without international collaboration and these entirely domestic papers have won 3,544 citations for an average of 82.4 citations per paper. Chinese authors have collaborated with authors from 45 countries in 177 papers published in *Nature* and these have won 30,623 citations for an average of 173 cites per paper. Chinese authors have collaborated with authors from 10

Table 3. Journals used by Indian and Chinese authors to publish papers with 100 or more citations

Journal	Country	China		India		Impact factor*
		No. of papers	Sum of citations	No. of papers	Sum of citations	
Nature	England	72	28,864	28	7,350	28.751
Science	USA	81	20,076	16	4,409	26.372
Phys. Rev. Lett.	USA	110	19,531	65	11,171	6.944
Lancet	England	50	14,662	13	4,380	28.638
J. Am. Chem. Soc.	USA	92	13,837	15	2,279	7.885
Appl. Phys. Lett.	USA	67	12,338	6	915	3.596
Angew. Chem. Int. Ed. Engl.	Germany	69	11,499	11	2,138	10.031
N. Engl. J. Med.	USA	32	9,726	5	1,082	52.589
Advan. Mater.	Germany	62	9,333	3	890	8.191
Chem. Mater	USA	43	6,413	9	1,532	4.883
Proc. Natl. Acad. Sci. USA	USA	32	4,753	7	1,086	9.598
Phys. Lett. B	The Netherlands	24	4,345	8	4,465	4.189
J. Phys. Chem. B	USA	27	4,170	10	1,393	4.086
Inorg. Chem.	USA	28	4,062	4	502	4.123
Phys. Lett. A	The Netherlands	20	3,753	1	110	1.711
Chem. Commun.	England	25	3,380	9	1,389	5.141
Am. J. Hum. Genet.	USA	13	3,345	2	310	11.092
J. Phys. G. Nucl. Particle Phys.	England	2	3,318	2	3,301	3.485
Anal. Chem.	USA	16	3,189	–	–	5.287
Mat. Sci. Eng. R.	Switzerland	13	2,992	–	–	14.400
Cancer Res.	USA	20	2,846	–	–	7.672
Nature Genet.	USA	17	2,837	4	685	25.556
Phys. Rev. B	USA	19	2,822	8	1,054	3.172
J. Clin. Oncol.	USA	6	2,488	4	1,112	15.484
Langmuir	USA	18	2,484	4	453	4.009
Phys. Rev. A	USA	18	2,419	2	260	2.893
Nucl. Instrum. Methods Phys. Res. A	The Netherlands	7	2,303	5	2,853	1.114
J. Biol. Chem.	USA	14	2,302	4	494	5.581
Astrophys. J.	USA	14	2,287	7	1,212	6.405
Chem. Phys. Lett.	The Netherlands	16	2,221	4	582	2.207
Chaos Soliton Fractal	England	14	2,205	–	–	3.025
Nature Med.	USA	13	2,172	1	223	26.382
Acc. Chem. Res.	USA	11	2,138	8	1,946	16.214
Gastroenterology	USA	11	2,072	–	–	11.673
J. Am. Med. Assoc.	USA	10	2,070	3	432	25.547
Macromolecules	USA	16	2,034	1	270	4.411
Chem. Rev.	USA	10	2,020	15	4,264	22.757
J. High Energy Phys.	Italy	–	–	14	3,234	5.659

317 journals were used by Indian researchers to publish 776 papers which have been cited at least 100 times.
457 journals were used by Chinese researchers to publish 2,260 paper which have been cited at least 100 times.
*Impact factor values taken from *Journal Citations Reports* (*JCR*) 2007.

Table 4. Journals publishing Indian and Chinese papers with 100 or more citations distributed by impact factor range

Impact factor range	India			China		
	No. of journals	No. of papers	Sum of citations	No. of journals	No. of papers	Sum of citations
$> 0 \leq 1$	12	16	2,324	36	65	10,333
$> 1 \leq 2$	57	74	14,221	123	228	36,655
$> 2 \leq 3$	64	110	18,240	112	257	40,411
$> 3 \leq 4$	44	90	22,154	83	293	51,351
$> 4 \leq 5$	33	86	16,060	47	271	40,741
$> 5 \leq 10$	65	231	43,517	90	613	96,038
$> 10 \leq 20$	27	66	12,843	36	263	54,683
$> 20 \leq 30$	9	89	24,048	12	213	59,816
> 30	3	10	1,757	2	34	10,007
Not listed	3	4	633	16	23	3,177
Total	317	776	155,797	557	2260	403,212

countries to write 10 or more papers. The major collaborators come from USA (133), England (40), Japan (29) and Germany (27).

The 115 papers from India in *Nature* have been cited 8,828 times for an average of 76.7 citations per paper. Of these, 65 papers are written exclusively by Indian authors without foreign collaborators, of which five have been cited at least 100 times. The 65 exclusively Indian papers have been cited 1,691 times for an average of 26 citations per paper. Indian authors have written 50 papers in collaboration with researchers from 35 countries, USA (38), England (12) and France (10) being the most preferred among them. These 50 papers were cited 7137 times for an average of 142.7 cites per paper.

The 310 papers published by Chinese researchers in *Science* in the 10 years have been cited 26,522 times for an average of 85.6 citations per paper, far less than the average number of citations for papers published by Chinese authors in *Nature*. Of these, 104 papers were written exclusively by Chinese authors and these have been cited 4,105 times for an average of 39.5 citations per paper. Chinese researchers have collaborated with researchers from 58 countries to write 206 papers in *Science*, with nine of them accounting for at least 10 papers. The prominent collaborating countries are USA (161), Germany (33) and France (28). These 206 papers were cited 22,417 times for an average of 108.8 cites per paper.

The 101 papers written by Indian researchers in *Science* have received 6,585 citations for an average of 65.2 citations per paper. Of these, 38 papers were written exclusively by Indian researchers and these were cited 605 times for an average of 15.9 citations per paper. Indian researchers have collaborated with authors from 64 countries in publishing 63 papers in *Science* and these were cited 5,980 times for an average of 94.9 cites per paper. The prolific collaborating countries are USA (48), England (16), Germany (9) and Japan (9).

In the ten years considered Chinese researchers have published 1,415 papers in *Physical Review Letters* (impact factor 6.944) and these papers have been cited 54,079 times till 16 March 2010, for an average of 38.2 cites per paper. Of these, 335 papers were written exclusively by Chinese authors (with no foreign collaborators) and these have been cited 10,361 times for an average of 30.9 cites per paper. The 1,080 papers in *Physical Review Letters* written by Chinese and foreign researchers were cited 43,718 times for an average of 40.5 cites per paper. The collaborating authors come from 51 countries, the most prominent among them being USA (803 papers), Germany (446), Russia (411) and France (301).

During the same period Indian researchers had published 842 papers in *Physical Review Letters*, with 264 of them written exclusively by researchers working in India and the rest in collaboration with authors from 46 countries, the prominent among them being USA (426 papers), Russia (279), and Germany, China and South Korea (254 each). The 842 papers were cited 31,153 times (up to 16 March 2010) for an average of 37 cites per paper. The 264 entirely domestic papers were cited 6,765 times for an average of 25.6 cites per paper. The 578 internationally coauthored papers were cited 24,388 times for an average of 42.2 cites per paper.

Chinese scientists have published 832 papers in 1998–2007 in the *Journal of the American Chemical Society* (impact factor 7.885) and these have been cited 40,488 times for an average of 48.7 cites per paper. Of these, 307 papers were written in collaboration with foreign authors. The 525 entirely domestic papers were cited 27,436 times for an average of 52.3 cites per paper. The 307 papers written with overseas co-authors have been cited 13,052 times for an average of 42.5 cites per paper. The co-authors are mainly from USA (176 papers), Japan (51) and Germany (30).

During the same 10 years, Indian researchers published 199 papers in the *Journal of the American Chemical Society*, of which 70 were co-authored with foreign researchers, mostly working in USA (37), Germany (10) and Japan (8). The 199 papers were cited 8,017 times up to 16 March 2010, for an average of 40.3 cites per paper. The 129 entirely domestic papers were cited 5016 times, for an average of 38.9 cites per paper. The 70 papers with foreign collaborators accumulated 3001 citations for an average of 42.9 cites per paper.

Clearly, both India and China papers resulting from international collaboration are cited much more often than those written exclusively by home country authors. (One exception is the Chinese papers published in the *Journal of the American Chemical Society*, where papers written with foreign collaborators were cited less often than those without foreign coauthors.) We have noticed the trend of papers with international collaboration appearing in higher impact journals and getting cited more often than purely domestic papers in our earlier studies as well[24,25].

It is not always that highly cited papers appear in high impact journals. For example, a paper from China published in the *Quarterly Journal of the Royal Meteorological Society* (impact factor 2.89) has received 1,029 citations. A Chinese paper published in *Process Biochemistry* (impact factor 2.33) has been cited 883 times.

Distribution by journal country

The countries of origin of journals in which India and China publish their highly cited papers are shown in Table 5. Clearly, USA, England and the Netherlands are the homes of journals often used by Indian and Chinese researchers to publish their better-cited papers. Papers published in the home-country journals rarely become highly cited. Of the more than 770 highly cited papers from India, only two were published in an Indian journal

Table 5. Journals publishing papers from India and China with 100 or more citations distributed by journal country

	India			China		
Country	No. of journals	No. of papers	Sum of citations	No. of journals	No. of papers	Sum of citations
USA	140	397	79,415	260	1323	223,641
Australia	2	2	210	1	1	152
Austria	0	0	0	1	1	261
Canada	2	3	432	3	3	611
Denmark	3	3	810	1	1	176
England	92	215	41,278	158	472	102,360
France	3	6	725	3	7	943
Germany	13	27	5071	18	171	27,178
Greece	0	0	0	2	2	236
India	1	2	335	0	0	0
Ireland	3	4	518	2	2	303
Italy	1	14	3234	1	1	169
Japan	1	1	110	6	6	1,092
The Netherlands	44	81	19,181	69	192	32,416
New Zealand	0	0	0	1	1	111
Peoples Republic of China	0	0	0	9	14	1,845
Romania	0	0	0	1	1	327
Singapore	3	6	2,115	2	9	2,108
Spain	1	1	142	0	0	0
Switzerland	8	14	2,221	19	53	9,283
Total	317	776	155,797	557	2260	403,212

Table 6. Collaborating countries in papers with 100 or more citations from India and China during 1998–2007

	India			China		
Country	No. of papers	Sum of citations	Cites per paper	No. of papers	Sum of citations	Cites per paper
India	776	155,797	200.8	82*	20,175*	246.0
USA	303	75,448	249.0	804	165,072	205.31
Germany	129	40,934	317.3	234	57,666	246.4
England	108	37,243	344.8	204	61,418	301.1
France	105	35,888	341.8	181	48,919	270.3
Japan	83	32,198	387.9	186	50,452	271.2
Russia	79	30,638	387.8	103	24,564	238.5
Sweden	56	25,778	460.3	75	20,191	269.2
Italy	51	25,142	493.0	97	25,970	267.7
Canada	49	24,985	509.9	132	31,882	241.5
Switzerland	52	24,369	468.3	71	18,853	265.5
Spain	35	21,262	607.5	51	13,614	267.0
Peoples Republic of China	81*	19,801*	244.5	2260	403,212	178.4
Finland	15	17,979	1198.6	22	8,397	381.7
Scotland	18	16,473	915.2	54	16,767	310.5
Australia	41	16,425	400.6	120	29,177	243.1
South Korea	49	16,376	334.2	79	18,574	235.1
Israel	42	14,024	333.9	42	20,335	484.2
Brazil	56	11,328	202.3	71	15,066	212.2

*The differences in number of papers and sum of citations are because data for China were collected a month later than those for India.

(Pandey, A. *et al.*, *Curr. Sci.*, 1999, **77**, 149–162; Majumdar, S. N., *Curr. Sci.*, 1999, **77**, 370–375). China fared slightly better with 14 papers published in nine Chinese journals winning more than 100 citations.

Many of the highly cited papers from both India and China were written in collaboration with researchers from other countries, mainly USA, Germany, England, France and Japan. In Table 6 we present data on the number of papers written collaboratively with foreign authors. Chinese researchers have collaborated with researchers in 93 countries and Indian researchers have collaborated with researchers in 91 countries to write papers that eventually received 100 or more citations.

Table 7. Indian papers with 100 or more citations distributed by institution

Institution	No. of papers	Sum of citations	Cites per paper	No. of papers with more than 100 authors	Sum of citations	Cites per paper
Tata Inst Fundamental Res, Mumbai	59	25,875	438.6	23	18,570	807.4
Indian Inst Sci, Bangalore	72	13,500	187.5	3	527	175.7
Jawaharlal Nehru Ctr Adv Sci Res, Bangalore	44	9,021	205			
Panjab Univ, Chandigarh	40	7,312	182.8	29	5,675	195.7
Banaras Hindu Univ, Varanasi	36	6,609	183.6	19	3,931	206.9
Bhabha Atom Res Ctr, Mumbai	35	6,176	176.5	20	4,200	210
Inter Univ Ctr Astron & Astrophys, Pune	26	5,370	206.5	1	162	162
Indian Inst Technol, Kanpur	25	5,207	208.3			
Harish Chandra Res Inst, Allahabad	24	4,975	207.3	1	110	110
Univ Hyderabad, Hyderabad	20	4,961	248.1			
Indian Inst Technol, Bombay	24	4,337	180.7	5	1,192	238.4
Natl Chem Lab, Pune	24	3,749	156.2			
All India Inst Med Sci, New Delhi	17	3,735	219.7			
Natl Ctr Biol Sci, TIFR, Bangalore	12	3,266	272.2			
Univ Delhi, New Delhi	18	3,110	172.8	7	1,436	205.1
Reg Res Lab, Thiruvananthapuram	18	2,661	147.8			
Jaslok Hosp & Res Ctr, Mumbai	3	2,411	803.7			
Inst Phys, Bhubaneswar	11	2,311	210.1	10	2,211	221.1
Indian Assoc Cultivation Sci, Kolkata	14	2,299	164.2			
Utkal Univ, Bhubaneswar	10	2,294	229.4	10	2,294	229.4
Variable Energy Cyclotron Ctr (BARC), Kolkata	10	2,211	221.1	10	2,211	221.1
Univ Jammu, Jammu	10	2,211	221.1	10	2,211	221.1
Univ Rajasthan, Jaipur	10	2,211	221.1	10	2,211	221.1
Indian Inst Technol, Delhi	13	1,995	153.5			
Indian Inst Technol, Kharagpur	13	1,984	152.6			
Indian Inst Chem Technol, Hyderabad	13	1,728	133			
Inst Bioinformat, Bangalore	8	1,570	196.25			
Inst Math Sci, Chennai	7	1,512	216			
Phys Res Lab, Ahmedabad	7	1,438	205.4			
Indian Stat Inst, Kolkata	8	1,344	168			
Bose Inst, Kolkata	9	1,300	144.4			
King Edward Mem Hosp, Pune	6	1,259	209.8			
Natl Phys Lab, New Delhi	5	1,256	251.2			
Raman Res Inst, Bangalore	8	1,216	152			
Indian Inst Technol, Madras	7	1,158	165.4			
Jadavpur Univ, Kolkata	8	1,126	140.7			
Univ Roorkee, Roorkee	7	1,118	159.7			
Indian Agr Res Inst, New Delhi	3	1,004	334.7	1	677	677

Distribution by institution

Researchers from 228 institutions in India have contributed to more than 770 papers, with 100 or more citations coming from India (Table 7). Prominent among them are the Indian Institute of Science (IISc), Bangalore (72 papers and 13,500 citations), Tata Institute of Fundamental Research (TIFR), Mumbai (59 and 25,875), and Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore (44 and 9021). Among the Universities, Panjab University, Chandigarh (40 and 7,312) and Banaras Hindu University (BHU), Varanasi (36 and 6,609) figure prominently. But, 23 of the 59 papers from TIFR, 29 of the 40 papers from Panjab University and 19 of the 36 papers from BHU are internationally co-authored and have more than 100 authors. These are mostly papers in high energy physics. It is difficult to assess the part played by the Indian authors in papers with a large number of authors. All the 10 papers from Utkal University, Bhubaneswar; University of Rajasthan, Jaipur and University of Jammu, Jammu are also of this kind, as well as 10 of the 11 papers from Institute of Physics (IOP), Bhubaneswar.

We would like to point out that the papers assigned to JNCASR include at least three written by authors primarily working in other institutions:

- Kaul, R. and Balaram, P., Stereochemical control of peptide folding. *Bioinorg. Med. Chem.*, 1999.
- Maitra, U., Mukhopadhyay, S., Sarkar, A., Rao, P. and Indi, S. S., Hydrophobic pockets in a nonpolymeric aqueous gel: Observation of such a gelation process by color change. *Angew. Chem., Int. Ed. Eng.*, 2001.
- Sudeep, P. K., Ipe, B. I., Thomas, K. G., George, M. V., Barazzouk, S., Hotchandani, S. and Kamat, P. V., Fullerene-functionalized gold nanoparticles. A self-assembled photoactive antenna-metal nanocore assembly. *Nano Lett.*, 2002.

Table 8. Distribution of highly cited papers by institutional type

Institutional type	No. of institutions	No. of papers	Sum of citations	Cites per paper
Academia	107	453	82,201	181.5
DAE	10	152	44,692	294.0
CSIR	20	105	15,530	147.9
DST	13	86	15,459	179.8
Private Hospitals	16	26	6,694	257.5
NGO	10	19	3,637	191.4
ICMR	9	12	2,088	174.0
ICAR	5	7	1,574	224.9
Department of Space	2	7	1,438	205.4
Company	8	9	1,280	142.2
International	5	7	1,161	165.9
State Governments	7	7	999	142.7
DBT	3	8	967	120.9
MoES	1	3	440	146.7
MoWR	1	3	352	117.3
School	1	2	351	175.5
MoEF	3	2	301	150.5
ICSSR	1	1	248	248.0
DRDO	1	2	213	106.5
Central Government Hospitals	1	1	184	184.0
MoP	1	1	135	135.0
MoC	1	1	133	133.0
MoCIT	1	1	116	116.0
MNCs	1	1	100	100.0

Balaram and Maitra are professors at IISc, but in these papers they have given JNCASR as an additional affiliation. In the third paper (DOI: 10.1021/nl010073w) the byline includes two addresses, viz. Photochemistry Research Unit, Regional Research Laboratory (CSIR), Thiruvananthapuram 695 019, India, and Notre Dame Radiation Laboratory, Notre Dame, Indiana 46556; and yet *Web of Science* lists JNCASR as an additional address. It is likely that George had indicated (in a footnote) his affiliation to JNCASR.

For some reason, often the rendering of JNCASR in the address field takes the form: Indian Institute of Science, Jawaharlal Nehru Centre for Advanced Scientific Research, Chemistry and Physics of Materials Unit, Bangalore 560 064, Karnataka, India.

Another tricky institutional entry concerns Panjab University, Chandigarh. In some places the rendering in *Web of Science* takes the form 'Punjab University, Chandigarh' or 'Punjabi University, Chandigarh'. Punjab University is in Lahore, Pakistan, and Punjabi University is in Patiala, Punjab, India. Wherever Chandigarh follows the university name, we checked the original paper online and found the correct university name to be Panjab University, Chandigarh. This is a mistake introduced at the data entry stage at Thomson Reuters.

Many Department of Atomic Energy (DAE) laboratories figure prominently in Table 7. Apart from TIFR, we find Bhabha Atomic Research Centre (35 highly cited papers and 6,576 citations), Harish Chandra Research Institute (24 and 4,975), National Centre for Biological Sciences (12 and 3,226), Institute of Physics (11 and 2,311), Variable Energy Cyclotron Centre, Kolkata (10 and 2,211) and Institute of Mathematical Sciences (7 highly cited papers and 1,512 citations).

Table 8 provides data on the distribution of these papers by institutional type. During the 10 years considered only three sectors, viz. academia (453 papers), Department of Atomic Energy (152) and CSIR (105) have published more than 100 papers that have gone on to be cited at least 100 times. Next is the Department of Science and Technology with 86 papers that have been cited at least 100 times. However, the average number of citations for papers from CSIR and DST laboratories is far below the all-India average. Even papers from academia as a whole (including IISc and Indian Institutes of Technology (IITs) at Bombay, Delhi, Kharagpur and Madras) have received fewer citations than the national average. Papers from both DAE and private hospitals (26 papers), however, have significantly higher cites per paper than the all-India average. In the case of DAE, part of this comes from participation by its scientists in high energy particle physics experiments involving large international teams. For example, the five most highly cited papers of TIFR have the same title 'Review of particle physics', were written by an international team of more than 100 authors, were published between 1998 and 2006, and have together been cited 14,565 times. A sixth paper on GEANT4 with more than 100 authors published in *Nuclear Instruments and Methods in Physics Research A* has been cited 1,758 times. If we remove such highly

Table 9. Chinese papers with 100 or more citations distributed by institution

Institution	No. of papers cited at least 100 times	Sum of citations	Cites per paper	No. of papers with more than 100 authors	Sum of citations	Cites per paper
Univ Hong Kong, Hong Kong	301	66,381	220.53	3	3946	1315.3
Chinese Univ Hong Kong, Hong Kong	223	45,686	204.87	3	3946	1315.3
Peking Univ, Beijing	186	34,657	186.33	20	4789	239.45
Univ Sci & Technol China, Hefei	131	22,903	174.83	35	6075	173.57
Hong Kong Univ Sci & Technol, Hong Kong	128	26,743	208.93	3	3946	1315.3
Tsing Hua Univ, Beijing	121	19,566	161.7	8	1547	193.37
City Univ Hong Kong, Hong Kong	96	16,617	173.09			
Fudan Univ, Shanghai	89	15,348	172.45	2	1788	894
Nanjing Univ, Nanjing	86	12,556	146			
Chinese Acad Sci, Inst Chem, Beijing	80	13,535	169.19			
Chinese Acad Sci, Inst High Energy Phys, Beijing	70	17,152	245.03	17	2836	166.82
Chinese Acad Sci, Inst Phys, Beijing	66	9,749	147.71			
Zhejiang Univ, Hangzhou	61	10,330	169.34	7	2618	374
Shanghai Jiao Tong Univ, Shanghai	53	8,217	155.04	5	677	135.4
Zhongshan Univ, Guangzhou	46	7,051	153.28	1	177	177
Jilin Univ, Changchun	46	7,013	152.46			
Sun Yat Sen Univ, Guangzhou	46	6,197	134.72	1	224	224
Hong Kong Polytech Univ, Hong Kong	41	6,386	155.76			
Queen Mary Hosp, Hong Kong	33	7,789	236.03			
Chinese Acad Sci, Shanghai Inst Biol Sci, Shanghai	31	5,542	178.77	1	691	691
Nankai Univ, Tianjin	31	4,812	155.23	3	371	371
Beijing Normal Univ, Beijing	30	7,519	250.63	4	4207	1051.75
Chinese Acad Sci, Inst Met Res, Shenyang	25	5,007	200.28			
Xiamen Univ, Xiamen	25	3,903	156.12			
Chinese Acad Sci, Shanghai Inst Organ Chem, Shanghai	24	3,604	150.17			
Chinese Natl Human Genome Ctr Shanghai, Shanghai	21	13,859	659.95	2	3322	1661
Chinese Acad Sci, Fujian Inst Res Struct Matter, Fujian	21	3,005	143.1			
China Inst Atom Energy, Beijing	20	4,298	214.9	13	2567	150.76
Chinese Acad Sci, Changchun Inst Appl Chem, Changchun	20	2,788	139.4			

Authors from 528 Chinese institutions have published papers with 100 or more citations.

cited papers written by large international teams (as outliers), then the average cites per paper for DAE will be much less than the present 294, the national average will be much lower than 200 and papers from institutions such as IISc and IITs will have higher average citation rates than the national average. The high citation rates of papers from IOP, Variable Energy Cyclotron Centre, University of Jammu, Utkal University and University of Rajasthan are also because of such international collaborations in particle physics.

The distribution of highly cited Chinese papers by institution is presented in Table 9. Some institutions have appeared under more than one name, e.g. Peking University and Beijing University. Chinese National Human Genome Centre Shanghai, Shanghai has been rendered in at least four variants. The institutes under the Chinese Academy of Sciences were not always rendered in a uniform fashion. It was earlier known as Academia Sinica. We spent considerable time to ensure that all papers from a given institution were attributed to it.

Twenty-nine Chinese institutions have published at least 20 papers that have gone on to be cited 100 times or more often. Among these six are in Hong Kong. Of the top seven institutions publishing a large number of highly-cited papers, four are universities in Hong Kong, the other three being Peking University, Beijing; University of S&T of China, Hefei, and Tshing Hua University, Beijing. Beijing and Shanghai are the two major centres of research in the mainland with seven and six of the 29 institutions located respectively, in these two cities. Other prominent centres of research in China are Changchun and Guangzhou (with two of the top 29 institutions in each of them), Hefei, Hangzhou, Nanjing, Fujian, Tianjin, Xiamen and Shenyang. Of the top 29 institutions, seven come under the Chinese Academy of Sciences and 19 are universities. China Institute of Atom Energy, Beijing; Chinese National Human Genome Centre Shanghai, Shanghai, and Queen Mary Hospital, Hong Kong complete the top 29 institutions.

In terms of citations, Chinese National Human Genome Centre Shanghai, Shanghai, tops the list with 660 cites per paper, followed by Beijing Normal University, Beijing (30 papers and 251 cites per paper), Chinese Academy of Sciences, Institute of High Energy Physics, Beijing (70 and 245), Queen Mary Hospital, Hong Kong (33 and 236), and University of Hong Kong, Hong Kong (301 papers and 220.5 cites per paper).

Single-author papers

Of the 776 highly cited papers from India, 53 are by single authors and these were written by 34 researchers. These were cited 10,988 times for an average of 207.3 cites per paper. Ashoke Sen (Harish Chandra Research Institute, Allahabad) leads the list with 12 single-author papers which together have been cited 3,039 times by 12 December 2009. Gautam Desiraju (University of Hyderabad; now at the Solid State and Structural Chemistry Unit, IISc) has six papers which have been cited 1,460 times. Thanu Padmanabhan (Inter University Centre for Astronomy and Astrophysics, Pune) has published three single-author papers which together have been cited 1,161 times.

On the other extreme, 103 highly cited Indian papers had at least 20 authors, eight of them had more than 500 authors, three had more than 1000 authors, and two had more than 2000 authors. These papers with a large team of authors had appeared in 36 journals and were almost always in the area of high energy physics, nuclear physics and astrophysics. There were also a few papers in genomics and medical surveys. There were 35 papers in *Physical Review Letters* (6,206 citations), five in *Nuclear Instruments and Methods in Physics Research A* (2,853 citations), four papers in *European Physics Journal C* (5,358 citations), four in *Physical Review D* (3,003 citations), four papers in *Lancet* (2,640 citations) and five papers in *Nature* (1,301 citations).

The overall leader among Indian researchers is C. N. R. Rao (29 papers and 5,518 citations). The average citation rate for his highly cited papers (190.3) is less than the Indian average, but, as pointed out earlier, if we leave out the highly cited papers by large international teams, it will be much above the Indian average. In all these papers he has one or more co-authors. In nine of these papers at least one co-author is from a laboratory outside India. The nine papers with international co-authors were cited 1,406 times and the 20 papers with Indian co-authors were cited 4,112 times. Unlike in the case of most others, Rao's papers co-authored with Indian researchers are cited far more often on average than his papers co-authored with foreign collaborators. His 2004 paper in *Angew. Chem. Int. Edn. Engl.*, cited 845 times, is the second highest cited Indian paper in 10 years considered. Among others who have many highly cited papers are Ashoke Sen (17 papers, 3,786 citations) and Gautam Desiraju (13 papers, 3,339 citations). Kalyanmoy Deb (Indian Institute of Technology, Kanpur) had authored three highly-cited papers (2,007 citations), and one of them (*IEEE Transactions on Evolutionary Computation*, 2002, **6**, 182–197) became the highest cited Indian paper in the 10-year period considered (1,508 citations).

Of the 2260 highly cited papers from China, 81 are single-author papers written by 54 researchers. These 81 papers have accumulated 14,179 citations by 12 January 2010. J. H. He (Donghua University, Shanghai) has authored 17 of these papers which together have been cited 4,345 times. His research areas include nonlinear mechanics, computational methods in applied mechanics, chaos and fractals. J. D. Cao (South East University, Nanjing) has six single-author papers in the area of neural networks and these have been cited 850 times. S. J. Liao (Shanghai Jiao Tong University School of Naval Architecture and Ocean Engineering, Shanghai) has five single-author papers in the area of viscous flow and these have been cited 814 times.

Chinese researchers have published 202 highly cited papers with 20 or more authors, including 198 with foreign co-authors, during 1998–2007. These papers have appeared in 54 journals, including *Nature* (22 papers and 17,458 citations), *Physical Review Letters* (53 and 11,067), *Science* (12 and 3,137), *Physics Letters B* (12 and 1,940), *Lancet* (9 and 3,730) and *Nature Genetics* (8 papers and 1,318 citations). In all, these papers have been cited 62,111 times. Here again nuclear and particle physics papers dominate, but we also find a few papers on genomics, plant genetics and cancer. The three papers with more than a thousand authors that we find in the list of highly cited papers from India have authors from China as well.

We wanted to present data on Chinese authors with a large number of papers and citations, but we faced a considerable challenge in sorting out homonyms.

Distribution of highly cited papers by field

About 31.6% of highly cited Chinese papers (715 of 2,260 papers) have appeared in chemistry journals (not including journals in the areas of chemical engineering and polymer science), and these papers have received 107,887 citations. About 27% of Chinese papers cited 100 or more times (606 of 2,260 papers) have appeared in physics journals and these have been cited 106,328 times. These numbers have to be taken with caution as Thomson Reuters assigns subfield categories on the basis of journal titles and some journals are included in more than one category. Besides, papers in physics and chemistry that have appeared in multidisciplinary journals such as *Nature*, *Science* and *Proceedings of the National Academy of Science, USA*, are not included under these categories. Also 235 papers with 100 or more citations have appeared in materials science journals and these have won 35,857 citations. Besides, 91 papers with over 100 citations have appeared in nanoscience and nanotechnology journals (13,218 citations) and 11 papers with over 100 citations have appeared in metallurgy journals (1,733 citations). Among other areas in which Chinese scientists have published highly cited papers are general and internal medicine (99 papers and 27,673 citations), biochemistry and molecular biology (127 and 21,227), and electrical

and electronic engineering (91 papers and 14,677 citations).

Of the 776 papers from India which have been cited at least 100 times, 222 (28.6%) have appeared in physics journals, and these have received 58,482 citations; 160 papers (20.6%) have appeared in chemistry journals and have been cited 28,488 times, and 50 papers have appeared in materials science journals (8,036 citations). In addition, 47 highly cited papers in biochemistry and molecular biology from India have received 7,403 citations; 22 papers in general and internal medicine with at least 100 citations have received 5,999 citations; 15 highly-cited nanoscience and nanotechnology papers from India have received 2,891 citations, and 15 highly cited papers in electrical and electronic engineering have received 2,785 citations.

India seems to have done better than China in astronomy and astrophysics. India has 43 papers in this area with 100 or more citations (sum of citations 10,838) and China has 44 highly-cited papers (sum of citations 6,567). In mathematics (including statistics and probability), however, China's record appears to be far better: 57 papers with 100 or more citations and a total of 9,869 citations against India's five highly cited papers and 871 citations.

Conclusion

Many indicators have been developed to assess science and national performance of science. As the scientific enterprise matures, these indicators reflect the improved performance. There is a general perception that although the volume of research performed in some of the emerging countries is increasing, there is a lingering doubt about the quality of research performed in these countries. Often the poor (or less than the world average) citation rate is used to confirm this doubt. But always there are exceptions and even in a milieu of mediocrity, one finds a few stand-out performers and performances. It is with this thought that we wanted to identify highly cited papers from India and China. Whereas one can identify unambiguously the number of papers published in certain high impact factor journals, to find out highly cited papers, one has to wait for a few years. And therefore, it will be difficult from the data we have to be able to conclude unequivocally whether India and China are publishing a larger number of better-cited papers in recent years than before. But clearly we can identify researchers who have published papers that have been cited a large number of times.

Are India and China really on the path to world leadership in science? It looks a distinct possibility, especially when the West is going through a period of recession and mounting unemployment, and both China and India are recording high growth rates in both their economies and in scientific research. But China and India have a long way to go. When asked if the balance of economic power is shifting away from the US to India and China, Sam Pitroda[26], Advisor to India's Prime Minister on Infrastructure, Innovation and Information, said, 'I don't think so. I don't think people realize the amount of assets that have been created in the US over the last 50 years in terms of roads, infrastructure, and universities. We will take a long time to bridge that gap. Look at the think tanks in the US. It will take a long time for China and India to catch up. We still have basic problems like lack of water and sanitation'. The situation is not very different in science.

The proportion of papers winning 100 or more citations is as good an indicator as any. Only 0.32% of Indian research papers and 0.4% of Chinese research papers published in refereed journals indexed by Thomson Reuters have gone on to accumulate 100 or more citations. The figures for some selected institutions (chosen at random) are: University of Southern California, USA, 3.47%; Brown University, USA, 3.11%; Rutgers State University, USA, 2.98%; University of Amsterdam, The Netherlands, 2.85%; University of Leiden, The Netherlands, 2.5%; University of British Columbia, Canada, 2.48%; University of Tokyo, Japan, 2.4%; University of Heidelberg, Germany, 2.34%; Universidad Autónoma de Madrid, Spain, 2.18%; University of Melbourne, Australia, 1.85%; University of Grenoble, France, 1.84% and University of Southampton, UK, 1.79%. Both India and China have a long way to go indeed. But what is heartening is that the production of research papers is increasing in India and even more so in China. The next step is for researchers in the two countries to write papers that will be cited far more often than now. As Chairman Mao wrote[27], 'Every quality manifests itself in a certain quantity, and without quantity there can be no quality'.

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ACKNOWLEDGEMENTS. We are grateful to Dr Wu Yishan, ISTIC, Beijing for helping us to identify the Chinese institutions referred to by different names in *Web of Science* (and possibly in the journals). Prof. B. Viswanathan, Catalysis Society of India for helpful discussions and Subbiah Gunasekaran, Central Electrochemical Research Institute, Karaikudi for help in verifying data. S.A. thank the National Institute of Technology, Rourkela and Madhan for the hospitality provided. S.A. was a Visiting Professor at the Institute of Mathematical Sciences, Chennai when work was commenced on this paper.

Received 11 April 2010; revised accepted 27 July 2010