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Comparisons of the structure and infrastructure of Chinese and Indian Science and Technology ☆

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Abstract

A comparison was made of the research output literatures of India and China. Both bibliometric and computational linguistics approaches were used in the comparison. China has rapidly outpaced India in both volume and citation performance of publications. China's rapid publication growth rate over the past two decades is continuing, while India's is re-starting after a relatively dormant period of almost two decades.
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1. Introduction

The two preceding papers in this Special Issue examined the research output literature of India and China. Both have grown substantially in the last decade. How do they compare against each other, especially with regard to growth, quality, and specific attributes? The present paper addresses these issues.

2. What are the main technical thrusts at present?

The distribution and type of technical thrusts depends on the database and field selected. Two databases were examined (SCI and EC). In the SCI, the Subject Categories field was examined, and in the EC, the Controlled Vocabularies and Classification Codes fields were examined.

An analysis of the SCI Subject Categories for China during the 25 years from 1980 to 2005 showed a gradual shift of emphasis from multidisciplinary science, medicine, and life science in 1980 to materials, chemistry, and physics in 2005. For India, over the same period, most frequent topics shifted moderately from chemistry, physics, plant science, and medically-related to chemistry, physics, and materials—similar to that of China. See Table 1A for a specific listing of Subject Categories for India and China for 2005 in SCI.

Also, for 2005, the Controlled Vocabulary distributions in the EC are listed for India and China (see Table 1B). The thrusts of the two countries are remarkably similar using this metric. Both countries emphasize applied mathematics/modeling (Computer Simulation, Mathematical Models, Algorithms, Optimization, Finite Element Method [China]) and nanotechnology$_{[S1]}$ (X-ray Diffraction Analysis, Nanostructured Materials, Scanning Electron Microscopy, Transmission Electron Microscopy [China], Thin Films [India]). For further comparison, the Controlled Vocabulary distribution was performed on the USA records for 2005. In order of priority, the technical thrusts were: Mathematical Models, Computer Simulation, Algorithms, Optimization, Problem Solving, Proteins, Nanostructured Materials, Cells, Data Reduction, Synthesis (Chemical). The USA priority order is slightly closer to that of China than India, with the exception that the USA has some overt biology topics listed.

Finally, for 2005, the Classification Code distributions are listed for India and China in Table 1C. Overall, both countries focus on chemistry, physics, and applied mathematics, but the prioritizations are

Table 1A
Subject category distributions — SCI

India		China	
2005		2005	
Materials Science, Multidisciplinary	1634	Materials Science, Multidisciplinary	7091
Chemistry, Multidisciplinary	1553	Chemistry, Physical	4653
Chemistry, Organic	1542	Physics, Multidisciplinary	4478
Chemistry, Physical	1470	Chemistry, Multidisciplinary	4301
Biochemistry and Molecular Biology	1166	Physics, Applied	3823
Physics, Condensed Matter	971	Computer Science, Theory and Methods	3348
Physics, Multidisciplinary	953	Metallurgy and Metallurgical Engineering	3093
Physics, Applied	802	Biochemistry and Molecular Biology	2789
Engineering, Chemical	788	Physics, Condensed Matter	2738

Table 1B
Controlled vocabulary distributions — EC

India		China	
2005		2005	
Mathematical Models	1278	Computer Simulation	6873
Synthesis (Chemical)	906	Mathematical Models	6632
Computer Simulation	796	Algorithms	3224
X-ray Diffraction Analysis	553	Synthesis (Chemical)	3095
Nanostructured Materials	533	Nanostructured Materials	2806
Algorithms	524	Scanning Electron Microscopy	2592
Optimization	445	X-ray Diffraction Analysis	2507
Scanning Electron Microscopy	442	Optimization	2463
Reaction Kinetics	432	Finite Element Method	1919
Thin Films	382	Transmission Electron Microscopy	1831

mildly different. China emphasizes applied mathematics, chemistry, and physics, in that approximate order, whereas India emphasizes chemistry, physics, and applied mathematics, in that order.

3. What are the characteristics of the main publication journals?

Table 2A lists the SCI journals containing the most India papers, and Table 2B lists the SCI journals containing the most China papers. Based on the data downloaded, the number of papers published in each journal is shown in the first numerical column, the journal Impact Factor is shown in the second numerical column, the journal's theme is shown in the next column, and the date at which the journal's articles were accessed initially by the SCI is shown in the rightmost column.

For India, the highest ranking journals emphasize chemistry, veterinary, agriculture, and physics, in that order. For China, the order is materials (especially applied materials), physics, and chemistry, showing a definite difference in emphases. The journals common to both lists are Acta Crystallographica, Physical Review B, and Journal of Physical Chemistry B, a 12% overlap. For India, about 60% of the

Table 1C
Classification code distributions — EC

India		China	
2005		2005	
Chemical Reactions	2719	Chemical Reactions	9188
Organic Compounds	2505	Computer Applications	8639
Chemical Operations	2155	Applied Mathematics	8228
Inorganic Compounds	2154	Numerical Methods	7927
Physical Properties of Gases, Liquids and Solids	1816	Inorganic Compounds	7921
Atomic and Molecular Physics	1654	Physical Properties of Gases, Liquids and Solids	7116
Light/Optics	1595	Chemical Operations	6974
Electricity: Basic Concepts and Phenomena	1500	Light/Optics	6702
Applied Mathematics	1491	Organic Compounds	6114
Physical Chemistry	1479	Strength of Building Materials; Mechanical Properties	5671

Table 2A
Journals containing most India papers

India journal	# Papers	Impact Factor	Theme	SCI access date
Current Science	457	0.728	Multidisciplinary	1961
Indian Veterinary Journal	443	0.052	Veterinary	1977
Indian Journal of Animal Sciences	381	0.09	Veterinary	1976
Asian Journal of Chemistry	346	0.153	Chemistry	1995
Tetrahedron Letters	272	2.477	Chemistry	1959
Journal of the Indian Chemical Society	267	0.34	Chemistry	1946
Acta Crystallographica Section E—Structure Reports Online	242	0.581	Materials	2001
Indian Journal of Chemistry Section B—Organic Chemistry including Medicinal Chemistry	240	0.446	Chemistry	1976
Journal of Food Science and Technology—Mysore	217	0.123	Agriculture	1976
Physical Review B	187	3.185	Physics	1964
Indian Journal of Agricultural Sciences	172	0.084	Agriculture	1966
Indian Journal of Physics and Proceedings of the Indian Association for the Cultivation of Science	170	0.072	Physics	1968
Pramana—Journal of Physics	146	0.38	Physics	1990
Indian Journal of Chemistry Section A—Inorganic Bio-Inorganic Physical Theoretical and Analytical Chemistry	138	0.632	Chemistry	1976
Indian Journal of Pure and Applied Physics	134	0.495	Physics	1964
Journal of Applied Polymer Science	134	1.072	Materials	1965
Journal of Applied Physics	132	2.498	Physics	1937
Spectrochimica Acta Part A—Molecular and Biomolecular Spectroscopy	122	1.29	Chemistry	1973
Journal of the Geological Society of India	115	0.217	Geology	1970
Indian Journal of Heterocyclic Chemistry	114	0.312	Chemistry	1995
Bulletin of Materials Science	109	0.777	Materials	1986
Physical Review D	109	4.852	Physics	1970
Journal of Physical Chemistry B	107	4.033	Chemistry	1997
Physica B—Condensed Matter	107	0.796	Physics	1990
Physical Review Letters	105	7.489	Physics	1958

journals listed appear to be domestic Indian journals, whereas for China, about half of the journals listed appear to be domestic Chinese journals. In both cases, the journal Impact Factors are relatively low. For India, seventeen of the 25 journals listed have Impact Factor less than unity. For China, sixteen of the 25 journals listed have Impact Factor less than unity. Especially for China, almost all the journals recently accessed by the SCI/SSCI have Impact Factors below unity.

As a benchmark, the journals containing the most USA publications for 2005 (based on retrieval of the 50,000 most recent USA articles published in 2005) are shown in Table 2C, along with their Impact Factors. The medians of the Impact Factors listed for the three countries are: USA—4.74; China—.78; India—.58. The median USA Impact Factors is almost an order of magnitude greater than those of China or India, for the journals containing the most country papers.

Finally, there are major differences in the initial SCI/SSCI access dates between the two tables. For India, the median initial SCI/SSCI access date for the journals listed in Table 2A is 1973, while for China, the median initial SCI/SSCI access date for the journals listed in Table 2B is 1995. These differences in initial SCI/SSCI access date have profound implications for evaluating the growth in China's research

Table 2B
Journals containing most China papers

China journal	# Papers	Impact Factor	Theme	SCI access date
Acta Crystallographica Section E—Structure Reports Online	1494	0.581	Materials	2001
Acta Physica Sinica	1032	1.051	Physics	1999
Chinese Physics Letters	920	1.276	Physics	1989
Rare Metal Materials and Engineering	872	0.400	Materials	1997
Spectroscopy and Spectral Analysis	610	0.557	Physics	1999
Physical Review B	547	3.185	Physics	1964
Chemical Journal of Chinese Universities—Chinese	531	0.771	Chemistry	1995
Materials Letters	528	1.299	Materials	1985
Pricm 5: The Fifth Pacific Rim International Conference on Advanced Materials and Processing, Pts 1–5	520	0.000	Materials	2005
Chinese Science Bulletin	513	0.783	Science	1989
Applied Physics Letters	509	4.127	Physics	1962
Chinese Chemical Letters	504	0.355	Chemistry	1995
Chinese Physics	497	1.256	Physics	1981
Transactions of Nonferrous Metals Society of China	479	0.302	Materials	1995
Chinese Journal of Analytical Chemistry	459	0.397	Chemistry	1999
Communications in Theoretical Physics	453	0.872	Physics	1985
Acta Chimica Sinica	423	0.845	Chemistry	1980
Chinese Journal of Inorganic Chemistry	418	0.697	Chemistry	1999
Chinese Medical Journal	410	0.561	Medicine	1964
Journal of Physical Chemistry B	405	4.033	Chemistry	1997
High-Performance Ceramics Iii, Pts 1 and 2	398	0.000	Materials	2005
Journal of Rare Earths	346	0.249	Materials	1995
Physics Letters A	340	1.550	Physics	1979
Journal of Crystal Growth	338	1.681	Materials	1971
Chinese Journal of Chemistry	323	0.819	Chemistry	1995

output production. It has been tacitly assumed that China's rapidly increasing research literature output production has been due to some combination of increased research sponsorship and increased productivity. While these are undoubtedly important factors, at least some of the excess growth of China's research publications relative to India must have come from additional journals being accessed by the SCI/SSCI, rather than purely increased productivity or increased research sponsorship. The fraction of growth attributed to new journals accessed by the SCI/SSCI depends on the model of research publication dynamics selected, a topic beyond the scope of this study.

4. What is the temporal trend of main publication journals?

Fig. 1 presents the weighted Impact Factor for journals publishing the most Chinese and Indian articles during the period 1980 to 2005. (The weighted Impact Factor is calculated by evaluating the Impact Factor for the top 10 journals for a given year and then calculating an average that is weighted by the number of publications in each journal. Journals that did not have a reported Impact Factor were assigned a value of zero for the Impact Factor.). Since 1985, the weighted Impact Factor for Chinese articles has been greater than that for India, indicating that, on average, the Chinese are publishing in higher Impact

Table 2C
Journals containing most USA papers

Journal	# Papers	Impact Factor	Theme
Journal of Biological Chemistry	531	6.36	Chemistry
P Natl Acad Sci Usa	514	10.45	Science
Physical Review B	499	3.08	Physics
Astrophysical Journal	381	6.24	Physics
Journal of Applied Physics	348	2.26	Physics
J Am Chem Soc	340	6.9	Chemistry
Physical Review Letters	325	7.22	Physics
Applied Physics Letters	306	4.31	Physics
Journal of Chemical Physics	278	3.11	Physics
Journal Of Virology	268	5.4	Medicine
Infection and Immunity	207	4.03	Medicine
Intl Journal of Modern Physics A	206	1.05	Physics
Geophysical Research Letters	203	2.38	Geology
Journal of Physical Chemistry B	193	3.83	Chemistry
Physical Review D	190	5.16	Physics
Physical Review E	189	2.35	Physics
Journal of Neuroscience	177	7.91	Medicine
Cancer Research	167	7.69	Medicine
Health Care Financing Review	167		Medicine
Nucleic Acids Research	159	7.26	Medicine

Factor journals. The Chinese publication rate is not only much higher than that of India, but also the Chinese have maintained an advantage in the Impact Factor as well.

To further explore the quality of journals, Fig. 2 compares the number of Chinese and Indian publications in three high Impact Factor journals (Journal of the American Chemical Society, Physical

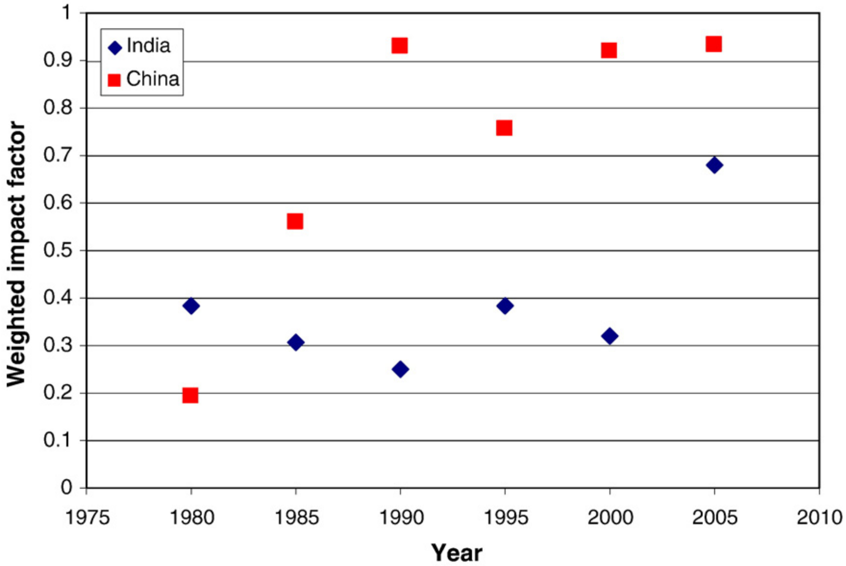

Fig. 1. Weighted Impact Factor for the top ten journals with Chinese or Indian authors.

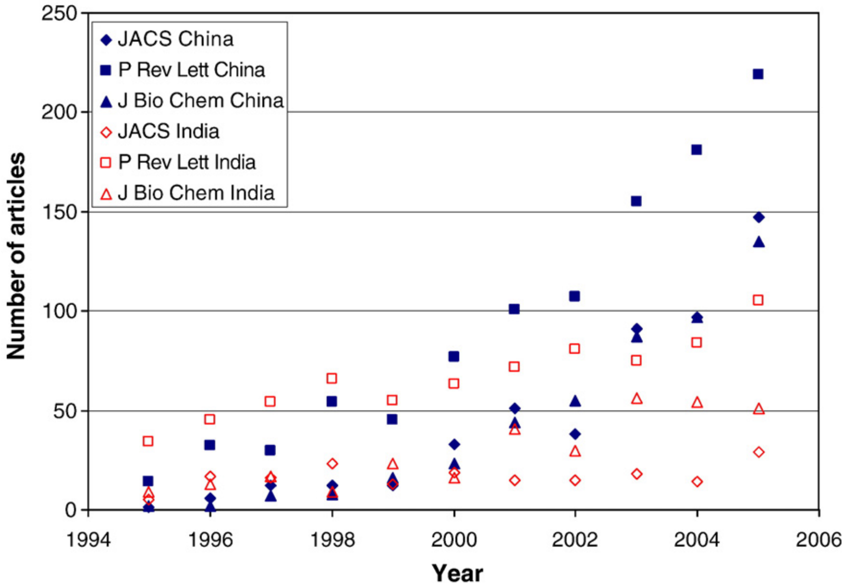

Fig. 2. Number of publications by Chinese or Indian authors in selected high Impact Factor journals as a Function of Time.

Review Letters, and Journal of Biological Chemistry) in three major technical disciplines. The Chinese publications are shown with the solid symbols, while the Indian publications are shown with the hollow symbols. The publication rate in each of these journals by Indian authors during the period shown has risen at a respectable pace. Publications by Chinese authors have shown a steady increase and have significantly outpaced those by India starting in 2000.

5. What is the impact of collaboration on publication quality?

Collaboration at the national level refers to papers that include at least one author with an India (or China) address and at least one author with a non-India (or non-China) address. The effect of collaboration on numbers of publications in four high Impact Factor journals is shown in Table 3. This

Table 3
Comparison of Chinese and Indian articles in 2005 for selected journals with and without collaboration

Journal	Impact Factor [a]	Ratio of articles	
		China and collaborators: China only	India and collaborators: India only
Nature	29.273	6.3	8.0
Science	30.927	6.5	4.0
Physical Review Letters	7.489	4.8	4.2
PNAS—USA [b]	10.231	3.9	2.8

[a] Based on 2005 Impact Factors.
[b] Proceedings of the National Academy of Science.

Table 4
Country publications over time

India				China			
1980		2005		1980		2005	
Country/Territory	Record count	Country/Territory	Record count	Country/Territory	Record count	Country/Territory	Record count
India	10,605	India	25209	Peoples R China	692	Peoples R China	72362
USA	183	USA	1745	USA	37	USA	5995
England	54	Germany	795	France	11	Japan	2411
Canada	45	Japan	587	Denmark	8	Germany	1422
Fed Rep Ger	41	England	503	Fed Rep Ger	5	England	1401
Japan	23	France	419	Netherlands	4	Canada	1175
Italy	20	South Korea	322	Sweden	3	Australia	1024
Australia	15	Peoples R China	310	England	2	France	866
France	15	Canada	248	Belgium	1	Singapore	799
Switzerland	13	Italy	222	Canada	1	South Korea	712
Sweden	12	Australia	215	Hong Kong	1	Taiwan	474

table presents the ratio of the number of articles with collaborators to those without collaborators. For example, in the journal Nature, there are eight times the numbers of articles for India that include collaborators as there are articles that include only Indian authors. This is a very dramatic result. The relatively high ratios for both China and India indicate that both of these countries benefit greatly from collaboration on publications in high Impact Factor journals.

6. Who are the main collaborating countries on publications?

For both China and India, the major collaborator for the past 25 years has been the USA (see Table 4). As of 2005, the USA collaborated on about 7% of India's research articles and about 8% of China's research articles. Also in 2005, the second highest collaborator with China was Japan, followed by Germany, England, Canada, and Australia. Collaboration between China and Japan is increasing—

Table 5
Citations of papers with Chinese and Indian authors for selected years

Year	China					India				
	Number of citations					Number of citations				
	Number of papers	Papers with more than 100 cites	Median of top 20	Median of top 1%	Median of total	Number of papers	Papers with more than 100 cites	Median of top 20	Median of top 1%	Median of tot
1980	692	3	37	96	1	10,606	16	117	59	2
1985	3105	20	172	131	1	10,632	17	130	66	2
1990	6991	36	209	101	2	11,563	19	145	68	3
1995	11,397	42	195	85	2	12,603	29	151	69	3
2000	29,294	63	199	70	3	16,197	22	128	55	2
2005	72,362	2	23	11	0	25,227	0	29	10	0

Japanese collaboration with China was non-existant in 1980, was about 1/5 of the USA contribution in 1985, and has increased to about 40% of the USA contribution in 2005.

The second highest collaborator with India is Germany, followed by Japan and England. Japan is also increasing its collaboration with India—the collaboration level was about 1/8 of the USA contribution in 1980, about 1/7 of the USA contribution in 1985, and has increased to about 1/3 of the USA contribution in 2005.

7. What are the characteristics of the most cited papers?

Table 5 compares citations of papers by Chinese and Indian authors for selected years. The citations were obtained in mid-2006 for papers published in the year listed in the first column. The numbers of papers listed in the first column for each country were used for normalization purposes. Most of the citation metrics are for papers considered as high quality (>100 citations and/or twenty highest cited papers for a given year and/or in the top 1% of cited papers for a given year), although the final column for each country lists median citations for all published papers for a given year.

The overall median for each country is quite low (although increasing slowly with time). By comparison, for research articles published in 1998, the median USA article received eight citations, the median German article received seven citations, the median Japanese article received six citations, the median South Korean article received four citations, and the median Iranian/Egyptian/Cuban article received three citations. On the other hand, the median Russian article and median Iraqi article received one citation.

For papers with more than 100 citations, China has been leading India in percentage of publications for over two decades. In 1980, China had only about 7% the number of total research publications as India, but had almost 20% of publications with 100 or more citations. By the year 2000, China had almost double the number of publications as India, but almost triple the number of papers with over 100 citations. However, as the collaboration results of Table 3 showed, the role played by collaborating countries in the papers published in high Impact Factor journals is large, and the contribution of India or China to these high impact papers is unknown. In some cases, these highly cited papers are multi-national high energy or astronomy experiments, or multi-national clinical trials, and may have hundreds of authors. The contribution of any author, with perhaps the exception of the lead author, to these types of papers cannot be ascertained without in-depth research on each paper.

China has about 50% more citations for the median of the top twenty cited papers than India over the time frame, and a slightly smaller ratio advantage for the median of the top 1% of cited papers. Whether this difference is due to low quality Indian publications and/or limited journal circulation and/or overly applied papers and/or technical field covered (i.e., number of researchers working in technical field and available to cite papers) cannot be determined at this point.

However, technical discipline covered must play some role. If a technical discipline contains a relatively small number of researchers, then citations will be limited no matter how good a particular paper. From the comparison of journals in which each country was publishing highly (Tables 2A and B), it was shown that India was publishing highly in some veterinary and agricultural journals, whereas China was concentrating on physics, chemistry, and materials. In the Journal Citation Reports, on the Web of Science, classes of journals are listed by discipline, and the Impact Factors for these journals are shown.

The highest Impact Factor listed for a journal in the following six technical discipline categories is shown after the category name: Agriculture, Dairy and Animal Science, 2.44; Agriculture, Multidisciplinary, 2.51; Physics, Applied, 15.94; Physics, Multidisciplinary, 30.25; Chemistry, Organic, 9.92; Chemistry, Multidisciplinary, 20.87. Thus, two of the main areas in which India is publishing, Agricultural and

A

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
physical and materials sciences (16030)	chemistry, molecular structure (7693)	chemical reactions, catalysis (5212)	analytical chemistry methods, spectral analyses (3277)
			catalytic reactions (1935)
		crystal and chemical structure, synthesis (2481)	
	materials and structural properties, thin films, ceramics (8337)	performance of metals, alloys, composites, ceramics (6564)	powders, microcrystalline materials, crystal growth, materials preparation (3748)
			metal alloys, ceramics (2816)
		thin film preparation, properties, and applications (1773)	
life sciences, mathematics (18969)	numerical modeling and simulation (11607)	mathematical and numerical methods, theoretical equations and models (6957)	modeling of systems and phenomena (4871)
			mathematical theory and application (2086)
		computational processing techniques, networks, information processing (4650)	
	Biology and medicine (7362)	health research, disease treatment, plant and environmental science (3649)	soils, plants, geoscience (2023)
			clinical treatment of diseases, occupational health, cancer research and treatment (1626)
		biochemistry and molecular biology, gene expression, pharmacology (3713)	gene expression and sequencing (1473)
			cell expression, pharmacology (7362)

Fig. 3. A — Taxonomy of China literature technical thrusts. B — Taxonomy of India literature technical thrusts.

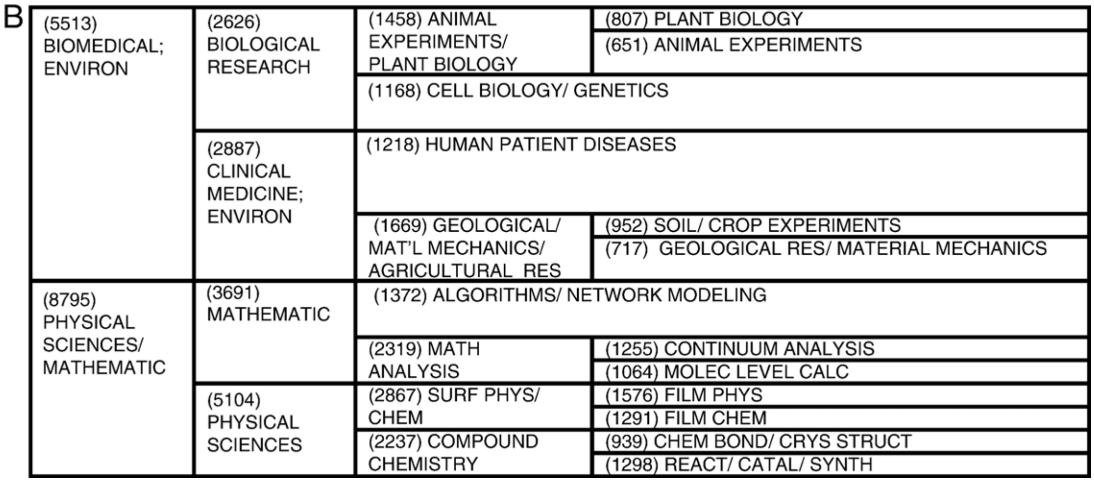

Fig. 3 (*continued*).

Veterinary Sciences, are intrinsically low Impact Factor disciplines. In Table 2A, of the four journals listed in Agricultural and Veterinary Sciences, the one with the highest Impact Factor is only .123. One can only conclude that India's emphasis in these disciplines, at least with respect to that of China, must be exerting a negative effect on citations at the high end and overall as well.

The characteristics of the most cited papers (citations greater than 150) and least cited papers for each country were examined from another perspective for two publication time periods (1979–1987, 1998–2003). The journals, authors, institutions, and collaborating countries were the metrics examined in comparing each group.

For both countries, the most cited papers were published in international journals, while the least cited were published mainly in domestic journals of the respective countries. For China, the broad technical areas covered in the highly and poorly cited groups were relatively similar. For India, the highly cited group focused on physics, chemistry, and medicine, while the poorly cited group had substantial additional representation from agricultural and veterinary sciences.

The names associated with the least cited papers for India and China were all Indian and Chinese, respectively, while the names associated with the highly cited papers were mixed. The institutions associated with the least cited papers for India and China were exclusively domestic. In India's case, for papers published decades ago, institutions associated with the most cited are mainly Indian, and are dominated by the Indian Institute of Technology and Indian Institute of Science. For relatively recent papers, institutions associated with the most cited are non-Indian, due to an anomaly. In China's case, in recent years, the institutions associated with the most cited papers are roughly half Chinese/half USA, showing the disproportionate contribution of USA institutions to highly cited Chinese research. Further, the two main Hong Kong universities have an order of magnitude higher relative representation (based on total publications) on the highly cited papers than their most visible Mainland counterparts (Chinese Academy of Science, Tsing Hua University, Zhejiang University).

Finally, the USA has been the predominant collaborator on the most highly cited papers for each country for decades. For India, the USA has increased its participation from 28% of the highly cited papers in 1979–1987 to 65% in 1998–2003, and for China, the USA had about five times the relative

Table 6
China–India citation comparison

Topic 1998 records	India records retrieved	India cites top ten—median	China records retrieved	China cites top ten—median	Winner
Physical sciences					
Crystal*	1096	68	1923	96	China+
Film*	665	50	1319	58	China
Oxidation	555	37	501	47	China+
Catalyst or catalysis or catalytic	468	45	615	67	China++
Algorithm*	322	33	505	36	Even
Nuclear	310	35	365	48	China+
Laser*	301	30	680	77	China++
Network*	290	28	434	54	China++
Thermodynamic*	269	43	326	48	Even
Dielectric*	240	25	199	50	China++
Computer*	229	24	336	41	China+
Magnetic field*	211	44	273	33	India+
Neutron*	160	41	166	43	Even
Spectromet*	134	20	317	39	China++
Sensor or sensors or sensing	134	23	244	28	China+
Acoustic*	102	13	119	17	China
Reaction*	1519	66	1997	97	China+
Molecular	871	65	1244	114	China+
Chemical*	923	46	1033	64	China+
Diffraction	404	42	881	56	China+
Environmental/agricultural sciences					
Soil*	449	24	177	55	China++
Rice	208	17	136	28	China++
Wheat	102	21	206	19	Even
Atmospher*	266	50	250	51	Even
Sea	147	27	153	34	China
River*	103	17	103	33	China+
Sediment*	171	22	183	43	China+
Ocean*	125	32	87	38	China
Climat*	122	21	109	52	China+
Maize	84	17	49	18	Even
Materials sciences					
Alloy*	359	27	848	47	China++
Composites	161	23	282	35	China+
Materials	467	39	618	61	China+
Metals or metallic	343	49	363	52	Even
Stainless steel*	79	10	69	16	China+
Polymer*	711	44	1023	100	China+
Copolymer*	157	18	286	35	China+
Ferromagnetic	66	29	111	19	India+
Silicon	187	18	411	73	China+
Doped	226	43	321	28	India+

Table 6 (*continued*)

Topic 1998 records	India records retrieved	India cites top ten—median	China records retrieved	China cites top ten—median	Winner
Life sciences					
Enzyme*	650	42	374	70	China++
Gene or genes or genetic or genetics	607	75	815	135	China++
Antibod*	292	32	247	76	China++
Cancer	199	24	257	76	China++
Biolog*	314	32	271	45	China+
Protein*	993	105	878	108	Even
Disease*	552	60	357	146	China+
Blood	382	40	347	125	China+
Liver	253	29	223	52	China+
Bacter*	310	30	152	48	China+

representation on the most highly cited papers expected based on its collaboration with all China research.

8. What are the main technical areas of emphasis?

About 35,000 research articles with at least one China author published in the 2004–2005 time frame were downloaded, and clustered by document similarity. The hierarchical taxonomy that resulted is shown in Fig. 3A. Likewise, about 15,000 research articles with at least one Indian author published in the 2005 time frame were downloaded and clustered, and the resultant taxonomy is shown in Fig. 3B.

The first hierarchical level of China's taxonomy was divided into the following two categories by the clustering algorithm: physical and material sciences (46% of the records) and life sciences, mathematics (54%). Ordinarily, the first hierarchical level of country taxonomies breaks into physical/engineering sciences and biomedical, with mathematics grouped along with the physical sciences. Because of China's efforts in biomedical terminology-driven mathematics such as genetic algorithms, genetic programming, evolutionary algorithms, the clustering algorithm associated mathematics more closely with life sciences than physical sciences. Thus mathematics was grouped with life sciences while examining the research output literature of China (refer China paper in this special issue). However, for the present comparison, the mathematics component of life sciences for China was converted to the physical sciences category, increasing the fraction of physical and materials sciences to 79% of total records. The life sciences component is then 21% of the total. These ratios comport well with the data in this paper that show China's strong materials emphasis, strong mathematics emphasis, and very modest emphasis on biomed.

In the second hierarchical level for China, the two physical sciences categories revolve around chemistry and materials. Physics does not stand out as a distinct separate category, but is mainly integrated with the materials category, with a substantial focus on physics of materials. There is a strong physics component in the optical region, and a strong effort as well on thin films and the associated nanotechnology. There is also a strong combined mathematics/physics effort in nonlinear dynamics. The effort devoted to agriculture and the environment appears subsumed under the fourth level category of soils, plants, geoscience, and represents about 6% of total effort.

Table 7
China–Australia citation comparison

Topic 1998 records	Australia records retrieved	Australia cites top ten—median	China records retrieved	China cites top ten—median	Winner
Physical sciences					
Chromatograph*	356	70	365	34	Australia++
Conductivity	120	39	297	33	Australia
Electronic	188	62	505	29	Australia++
Electrophoresis	179	72	169	35	Australia++
Finite element*	152	28	226	26	Australia
Gravity	92	29	75	23	Australia
Isotope*	177	77	160	45	Australia+
Magnetic field*	154	39	273	33	Australia
Mechanical	333	66	510	51	Australia+
Microscopy	458	111	726	56	Australia++
Molecular dynamics	49	42	82	20	Australia++
Nonlinear Or Non-linear	404	84	769	49	Australia+
Photon*	147	59	186	54	Australia
Polymer	212	58	523	50	Australia
Spectromet*	265	70	317	40	Australia++
Star or stars	170	98	97	35	Australia++
Superconduct*	116	32	283	32	Tie
Ligand*	419	208	475	84	Australia++
Environmental/agricultural sciences					
Climat*	282	99	109	53	Australia++
Earthquake*	18	22	31	9	Australia++
Floral	32	24	14	9	Australia++
Geochemi*	122	56	86	43	Australia+
Irrigation	57	21	17	8	Australia++
Ocean*	282	116	87	38	Australia++
Rock*	394	82	220	68	Australia+
Sea	338	94	153	34	Australia++
Seawater	55	45	24	12	Australia++
Sediment*	383	66	183	44	Australia+
Seedling*	139	38	58	21	Australia++
Tectonic	106	62	59	47	Australia+
Tomato*	41	37	14	14	Australia++
Volcan*	109	55	42	41	Australia+
Wheat	249	57	102	22	Australia++
Engineering sciences					
Aircraft	30	10	20	3	Australia++
Buckling	35	11	45	11	Tie
Engine*	191	50	212	20	Australia++
Heat treatment	31	17	97	17	Tie
Sinter*	47	23	122	19	Australia
Software	133	61	74	11	Australia++
Steel*	146	30	285	19	Australia+

Table 7 (*continued*)

Topic 1998 records	Australia records retrieved	Australia cites top ten—median	China records retrieved	China cites top ten—median	Winner
Engineering sciences					
Wastewater*	32	16	22	11	Australia+
Weld*	41	12	52	9	Australia
Iron	267	88	323	44	Australia++
Metal*	737	102	1359	98	Australia
Life sciences					
Antibod*	738	238	247	77	Australia++
Arterial	188	77	55	29	Australia++
Blood	968	181	347	127	Australia+
Cancer*	607	185	270	83	Australia++
Chromosome	253	205	107	52	Australia++
Clone*	272	123	168	71	Australia+
Dna	887	215	538	81	Australia++
Enzyme*	612	238	374	72	Australia++
Gene or genes or genetic	2001	347	811	137	Australia++
Liver*	352	129	226	52	Australia++
Lymphocyte*	347	191	92	47	Australia++
Peptide*	440	124	192	66	Australia++
Polymerase	319	93	140	73	Australia+
Protein*	1962	329	878	110	Australia++
Tissue*	999	183	370	86	Australia++
Tumor*	411	187	314	75	Australia++

For India, the first taxonomy level was divided into a biomedical/environmental category (about 39% of total records), and a physical sciences, mathematics category (about 61% of records). This reflects almost double the emphasis of China in the biomedical area, and will be reinforced by the relative investment strategy results of the final section of this paper. For China, mathematics represents about 1/3 of total effort, whereas for India, mathematics represents slightly over 1/4 of total effort. These differences in the mathematics ratios comport well with the findings from Table 1A (Subject Categories, with China's representation from Computer Science) and especially from Tables 1B (Controlled Vocabulary, with China's highest priorities given to mathematics) and 1C (Classification Codes, with some China priority given to mathematics).

India also emphasizes thin films and nanotechnology, with its physics strongly associated with surfaces/materials and phenomena in the visible. Its efforts in agriculture tend to concentrate in the Plant Biology and Soil/Crop Experiments categories, constituting about 12% of the total.

9. How do citations compare by technical category?

The previous section compared the investment allocation of China's and India's research using a document clustering approach. The present section compares the citation performance of China's and India's research, using the approach (of comparing citations of records retrieved using selected technical phrases representing broad research categories) described in the Introductory paper to this

Special Issue. The total SCI/SSCI citations for the retrieved records for each country for each phrase from 1998–mid 2005 were tabulated and analyzed. The results for the China–India comparison are shown in Table 6.

9.1. China–India comparison discussion

The first column in Table 6 is the query phrase, including variants in some cases. The second column is the number of 1998 India records retrieved for the query phrase, and the fourth column is the number of 1998 China records retrieved for the query phrase. The third column contains the median citations of the ten most cited Indian papers, while the fifth column contains the same type of information for China papers. The sixth column is the citation 'winner' in the technical discipline examined, with the pluses (+) denoting the strength of the lead. The patterns of winners in the different broad categories are examined, and judgments about leadership in each of the four major categories are made.

The phrases (technologies) are grouped by major category. The first group is Physical Sciences. Out of twenty phrases examined, representing diverse areas of Physical Sciences, China was a clear winner in fifteen, India led in one, and four were viewed as even. Clearly, China is the leader in Physical Sciences, based on top ten median numbers of citations.

The second group is Environmental Sciences. Out of ten phrases examined, China was the clear leader in seven, and three were considered even. Clearly, China is the leader in Environmental/Agricultural Sciences.

The third group is Material Sciences. Out of ten phrases examined, China was the clear leader in seven, India was the clear leader in two, and one was considered even. Clearly, China is the leader in Material Sciences.

The fourth group is Life Sciences. Out of ten phrases examined, China was the clear leader in nine, and one was considered even. Clearly, China is the leader in Life Sciences.

Thus, China was the clear leader in each major category, although there were (isolated) instances where India led in a sub-technology area. It should be re-emphasized that this citation comparison did not examine relative investment strategies. It focused only on technical areas that had similar magnitudes of investment.

9.2. China–Australia comparison

It was decided to compare the citation performance of the India–China 'winner' with that of Australia (refer Introductory paper of this Special Issue). As China emerged 'winner' in each major category, citation comparison of China–Australia was undertaken. The results of this comparison are shown on Table 7.

9.3. China–Australia comparison discussion

The first column in Table 7 is the query phrase, including variants in some cases. The second column is the number of 1998 Australia records retrieved for the query phrase, and the fourth column is the number of 1998 China records retrieved for the query phrase. The third column contains the median citations of the ten most cited Australian papers, while the fifth column contains the same type of information for China papers. The sixth column is the citation 'winner' in the technical discipline examined, with the pluses (+) denoting the strength of the lead. The patterns of winners in the different broad categories are examined, and judgments about leadership in each of the four major categories are made.

The phrases (technologies) are grouped by major category. The first group is Physical Sciences. Out of eighteen phrases examined, representing diverse areas of physical sciences, Australia was a clear winner in eleven, a close winner in six, and tied with China in one. Australia is clearly the leader in Physical Sciences, based on top ten median numbers of citations.

Table 8
China relative emphasis areas

Country	DMWord	India Abs count	China Abs count	India/China ratio	India/China normalized ratio
India	Linear Matrix	0	153	0	0
India	Puerarin	0	19	0	0
India	SARS	1	151	0.006623	0.019693
India	Multi-Walled Carbon	1	98	0.010204	0.030343
India	Periodic Solution*	5	250	0.02	0.059472
India	Influenza	2	85	0.023529	0.069967
India	Chemiluminesc*	6	200	0.03	0.089208
India	Gold Electrode	3	95	0.031579	0.093903
India	Discharge Capacity	5	154	0.032468	0.096545
India	Field Emission Scanning	6	170	0.035294	0.104951
India	Adiponectin	1	25	0.04	0.118944
India	MWNTS	5	124	0.040323	0.119903
India	Sufficient Condition	9	208	0.043269	0.128665
India	Nanowire	10	221	0.045249	0.134552
India	Transfection	10	215	0.046512	0.138307
India	Lyapunov	16	317	0.050473	0.150087
India	SIRNA	6	107	0.056075	0.166744
India	Nanospheres	7	116	0.060345	0.179441
India	Attractor	6	91	0.065934	0.196062
India	Hydrogen Storage	10	150	0.066667	0.19824
India	Chaotic Systems	7	100	0.07	0.208152
India	Support Vector	20	282	0.070922	0.210894
India	Support Vector Machine	12	164	0.073171	0.21758
India	Nanotube	34	456	0.074561	0.221716
India	Gastric Cancer	11	138	0.07971	0.237026
India	CNTS	16	193	0.082902	0.246516
India	Gene Delivery	6	69	0.086957	0.258574
India	Carbon Nanotube*	78	865	0.090173	0.26814
India	Single-Walled Carbon	11	118	0.09322	0.2772
India	XRD TEM	9	92	0.097826	0.290896
India	Immunofluoresce*	15	152	0.098684	0.293447
India	Cell Apoptosis	14	141	0.099291	0.295251
India	Encryption	9	85	0.105882	0.314852
India	SWNTS	7	64	0.109375	0.325238
India	Photoluminescence Properties	12	105	0.114286	0.33984
India	UV Light Or Ultraviolet Light	22	176	0.125	0.3717
India	Colorectal	20	151	0.13245	0.393854
India	Fullerene	21	158	0.132911	0.395225

Table 9
India relative emphasis areas

Country	DMWord	India Abs count	China Abs count	India/China ratio	India/China normalized ratio
India	Groundnut	51	1	51	151.6536
India	Leprosy	45	1	45	133.812
India	Chickpea	37	1	37	110.0232
India	Marker Enzyme*	36	1	36	107.0496
India	Buffalo	90	8	11.25	33.453
India	Jute	33	4	8.25	24.5322
India	Synthesized Compounds	106	16	6.625	19.7001
India	Millet	41	7	5.857143	17.4168
India	Husk	46	8	5.75	17.0982
India	Enzyme Production	28	5	5.6	16.65216
India	Coconut	40	8	5	14.868
India	Lambs	19	4	4.75	14.1246
India	Reduced Glutathione	94	22	4.272727	12.70538
India	Spectrophotometrically	57	15	3.8	11.29968
India	Sorghum	49	13	3.769231	11.20818
India	Gallbladder Cancer	15	4	3.75	11.151
India	Mosquitoes	22	6	3.666667	10.9032
India	Malaria	80	22	3.636364	10.81309
India	Sugarcane	30	9	3.333333	9.912
India	Plasticizers	16	5	3.2	9.51552
India	Wheat Bran	22	7	3.142857	9.3456
India	Warfare	15	5	3	8.9208
India	Violence	17	6	2.833333	8.4252
India	Sowing	42	15	2.8	8.32608
India	Thorium	42	17	2.470588	7.346541
India	Encephalitis	32	13	2.461538	7.319631
India	Bran	34	14	2.428571	7.2216
India	Goats	67	28	2.392857	7.1154
India	Cattle	133	61	2.180328	6.483423
India	Nuclear Power	17	8	2.125	6.3189
India	Mild Steel	61	29	2.103448	6.254814
India	Gallstone	14	7	2	5.9472
India	Ulcers	46	26	1.769231	5.260985
India	Aflatoxin	24	14	1.714286	5.0976
India	Legume	41	24	1.708333	5.0799
India	Fructose	51	32	1.59375	4.739175
India	Sheep	104	66	1.575758	4.685673
India	Carrot	17	11	1.545455	4.595564
India	Lymphadenopathy	18	12	1.5	4.4604
India	Optical Band Gap	50	34	1.470588	4.372941
India	Parasites	45	31	1.451613	4.316516
India	Anemia	44	31	1.419355	4.220594
India	Heavy Ion	144	108	1.333333	3.9648
India	Spectrophotometric	182	138	1.318841	3.921704

The second group is Environmental/Agricultural Sciences. Out of fifteen phrases examined, Australia was the clear leader in all fifteen. Australia was an obvious winner over China in Environmental/Agricultural Sciences.

The third group is Engineering Sciences. Out of eleven phrases examined, Australia was the clear leader in six, a close leader in three, and was tied with China in two. Although Australia is the winner in Engineering Sciences, China's focus on engineering and applied sciences can be seen, even compared to a first world country such as Australia.

The fourth group is Life Sciences. Out of sixteen phrases examined, Australia was the clear leader in all sixteen. This result is not only expected, but is further evidence that China is currently putting relatively more research effort into engineering and applied sciences than any other category, especially Life Sciences.

Thus, Australia was the clear leader in each major category, although there were (isolated) instances where China was tied in a sub-technology area. It should be re-emphasized that this comparison did not examine relative investment strategies. It focused only on technical areas that had similar magnitudes of investment.

10. What are the relatively unique investment allocations?

The taxonomy section compared investment allocations at different levels of resolution, mainly at a rather broad level. Even had the lowest level clusters been used for comparison, the resolution would still have been limited. The present section compares investment allocations at a very fine level, that of single phrase queries. This allows greater stratification of the results, and highlights very specific areas where each country has chosen to focus its investments, with a resolution at about the critical sub-technology level.

The approach used was as follows. Ten thousand articles each of India and China were downloaded from the SCI for 2006 (specifically, 10,000 articles most recent from Fall-2006). At the time the download occurred, the total number of India articles was 20,577 and the total number of China articles was 61,188. Thus, China had approximately three times the total number of research articles for 2006 as India.

A phrase frequency analysis was performed on each download, and the phrases were then combined. The ratio of frequencies for each phrase was tabulated. Phrases were ordered by ratio of occurrence in each country's download. Two bands were considered: phrases that had a large China/India frequency ratio and phrases that had a large India/China frequency ratio (the opposite ends of the spectrum). Select phrases in these bands were inserted into the SCI, and the actual numbers of records that contained these phrases (for the first 8 months of 2006) were obtained. The results are shown on Tables 8 and 9.

In Table 8, there are a number of distinct research investment emphasis groups for China relative to India. They include nanotechnology (Multi-Walled Carbon, Gold Electrode, MWNTS, Nanowire, Nanospheres, Nanotube, CNTS, Carbon Nanotube*, Single-Walled Carbon, XRD TEM, SWNTS, Fullerene), mathematics (Linear Matrix, Sufficient Condition, Support Vector Machine, Encryption) with a strong focus on nonlinear dynamics (Periodic Solution*, Lyapunov, Attractor, Chaotic Systems), medical disease research with a strong emphases on cancer (SIRNA, Transfection, Gastric Cancer, Cell Apoptosis, Colorectal) and viral (SARS, Influenza) treatments and secondary emphasis on diabetes (Puerarin, Adiponectin) treatment, luminescent phenomena (Chemiluminesc*, Immunofluoresc*, Photoluminescence Properties, UV Light or Ultraviolet Light), and energy storage (Discharge Capacity, Hydrogen Storage).

Similarly, there are a number of distinct research investment emphasis groups for India relative to China. They include agriculture (Chickpea, Jute, Millet, Husk, Coconut, Sorghum, Sugarcane, Wheat Bran, Aflatoxin, Legume, Carrot), veterinary (Buffalo, Lambs, Goats, Cattle, Sheep), medical (Leprosy, Gallbladder Cancer, Gallstone, Encephalitis, Ulcers, Lymphadenopathy, Parasites, Malaria, Mosquitos, Anemia), nuclear (Nuclear Power, Thorium), and optical (Spectrophotometrically, Optical Band Gap, Spectrophotometric).

11. Summary and conclusions

A comparison was made of the research output literatures for India and China. The following conclusions were drawn.

- As shown in the Introductory paper to this Special Issue, China has increased its total research article output by two orders of magnitude since 1980, whereas India has increased its research article output by 2.5 over the same time period, a factor of forty difference.
- Both countries have strong focus on applied mathematics and nanotechnology.
- For both countries, the majority of journals containing their most publications are domestic low Impact Factor journals. The median Impact Factors of the journals containing the largest number of USA publications are almost an order of magnitude larger than the similarly ranked journals for China or India.
- The median initial SCI access date of the journals containing the largest number of India publications is 1973, whereas the analogous date for China publications is 1995. Thus, at least some of the excess growth of China's research publications relative to that of India must have come from additional journals being accessed by the SCI/SSCI rather than purely increased productivity or increased research sponsorship.
- Since 1985, the weighted Impact Factor (based on top ten publishing journals) for Chinese articles has been greater than that for India. The Chinese are not only publishing substantially more than India, but they are publishing in higher Impact Factor journals as well.
- For the illustrative example of three key journals in physics, chemistry, and biology, publications by Chinese authors have significantly outpaced those by Indian authors since 2000.
- Both China and India benefit dramatically from external research collaboration by drastically increasing their publications in the highest Impact Factor journals.
- The main collaborators are the leading technology countries, especially the USA, Japan, Germany, and England. For India, the USA increased its participation from less than 2% of papers in 1980 to 7% in 2005, and for China, the USA increased its participation from 5% in 1980 to 8% in 2005.
- China outperforms India at the high citation end, independent of whether the metric used is papers with more than 100 citations, median of top twenty papers, or median of top 1% of papers.
- In comparing the most and least cited papers for each country, the following was found:
  - The most cited papers were published in international journals, while the least cited were published mainly in domestic journals of the respective countries.
  - Veterinary and agricultural sciences tended to be over-represented in India's poorly cited research.
  - Names associated with the least cited papers for India and China were all Indian and Chinese, respectively, while the names associated with the highly cited papers were mixed.

  - Institutions associated with the least cited papers for India and China were exclusively domestic.
  - The two main Hong Kong universities have an order of magnitude higher relative representation (based on total publications) on the highly cited papers than their most visible Mainland counterparts (Chinese Academy of Science, Tsing Hua University, Zhejiang University).
- China's technical emphases are on materials (especially nanostructures), applied mathematics (including nonlinear dynamics), and luminescent phenomena. Biomedicine has less of an emphasis, except for local diseases.
- India places more relative effort on biomedical, slightly less than China in applied mathematics, has strong interest in thin films and nanotechnology, physics strongly associated with surfaces/materials and optical spectra phenomena, and greater relative emphasis on veterinary and agricultural sciences.
- China outperforms India in citations across all major technical categories. In turn, Australia outperforms China in citations across the same categories using the same types of metrics.
- Relative to India, China emphasizes research in nanotechnology, mathematics (especially nonlinear dynamics), cancer and viral disease treatment, and luminescent phenomena.
- Relative to China, India emphasizes agriculture, veterinary, tropical diseases, nuclear power, and optical phenomena.
- The bottom line in this comparison is unmistakable. In 1980, India was light years ahead of China in volume and breadth of published research. For two decades, India's research output production stagnated. During that period, China's research production increased exponentially. Presently, China outperforms India substantially both in quantity and quality (as measured by the Impact Factor of research output), the gap is widening and shows no sign of abating if present Indian research policies are continued!

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