Impact of international cooperation and science and innovation strategies on S&T output: a comparative study of India and China

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India and China have made sizeable growth in publishing science and engineering research papers in co-authorship with international institutions and patents granted in collaboration with foreign inventors during the period 1997–2012. However, the growth in case of China is much higher in comparison to India. The pace of growth in publishing research papers in co-authorship with international and domestic institutions is more or less the same in case of China, whereas India has shown higher growth in publishing research papers in co-authorship with international institutions in comparison to those with domestic institutions. The share of India and China to research papers published in co-authorship with international institutions increased from 1.8% and 4.1% respectively, in 1997 to 3.5% and 14.7% respectively in 2012. China's share to patents granted in collaboration with foreign inventors increased from 0.94% in 1997 to 13.68% in 2012, compared to an increase of 0.56% to 7.39% in case of India. The analysis shows that China has harnessed the fruit of its international cooperation in S&T to its advantage, as reflected by significant increase in research papers co-authored with international institutions and patents granted in collaboration with foreign inventors in comparison to India.

Keywords: GERD, international collaboration, patents, research papers, science and innovation strategies.

THE economy in the 21st century is primarily knowledge-based and countries across the globe are expanding their reach by allocating significant portion of their gross domestic product (GDP) into science and engineering research. Research papers published and patents granted are two of the important indicators of S&T research output.

A significant growth in publishing science and engineering research papers with an average annual growth of 5.6% and 16.2% respectively, for India and China has been observed during the period 1995–2009 (ref. 1). The high growth of S&T output in China is possibly due to the implementation of numerous projects/programmes[2–4]. For example, Project 211 aimed at upgrading the standard of education in the universities wherein a large number of science and engineering professionals are trained, and key universities were geared to attain international standards[2]. The National Programme on Key Basic Research, codenamed '973', aimed at strengthening the basic research in line with national strategic targets[4], whereas Project 985 is aimed at creating new research centres, strengthening the infrastructure facilities and international collaborations[3]. China expanded its international collaboration by establishing contact with more than 150 countries and signed over 100 S&T agreements with almost equal number of countries[5]. The budgetary allocation under International Science and Technology Co-operation Programme (ISTCP) increased by fourfold during the period 2001–2008 (ref. 5). The National Natural Science Foundation (NNSF) of China has also doubled its resource allocations during the period 2001–2008 for international S&T cooperation[5]. Further, China Scholarship Council affiliated to the Ministry of Education provides 12,000 study-abroad scholarships per year and 10,000 study-in-China scholarships per year[6]. Student/staff exchange, joint-run schools (programmes) and joint research projects are some of the best practices adopted by the Chinese higher education institutions regarding internationalization[6].

The higher education system in India has witnessed a remarkable increase in plan expenditure from Rs 5.3 billion in 1980–85 to Rs 849.9 billion in 2007–12, which has further been increased by a margin of 30% during 2012–17 (ref. 7). Emphasis has been laid on 'excellence of higher education' in its Twelfth Five Year Plan (2012–17) with a focus on: (i) internationalization of education; (ii) encouraging private partnership; (iii) enabling environment that encourages research and innovation;

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(iv) improving the quality of faculty; (v) improved ICT for education delivery, and (vi) enhancing the employability[7,8]. Emphasis is also being laid on capacity building in terms of quality by establishing/upgrading state-of-the-art institutions[6]. Though there are many fellowship schemes for young researchers to pursue Ph D within the country, no major fellowship scheme is in place for students to pursue research abroad, unlike China which provides 12,000 fellowships to study abroad. Joint international programmes are however being implemented by various government scientific departments/agencies to promote innovation. The Department of Science and Technology (DST), Department of Biotechnology (DBT), Indian Council of Medical Research (ICMR), and Council of Scientific & Industrial Research (CSIR) have collaboration with over 70 foreign countries under bilateral, multilateral or regional framework modes for facilitating and strengthening interaction among researchers from academia, institutions and industries in areas of mutual interest.

China's medium and long-term plan for development of S&T aims at producing highly skilled manpower and establishment of advanced research centres for high-level R&D. The plan focuses on transforming China into an innovation-oriented society with R&D expenditure to be 2.5% of its GDP by 2020 (ref. 9). Emphasis of China's S&T policy is to support sustainable development and acceleration of technology commercialization. The 'Programme for Key International S&T Cooperation Projects', instituted during the Tenth Five-Year Plan, has been focusing on joint research with developed countries on the basis of equality, mutual benefit and sharing of intellectual property rights[4]. Furthermore, the achievements of a large number of Chinese students studying abroad provided an unprecedented favourable condition for international S&T cooperation in China[4]. Broad lessons that can be learnt by India in terms of the indicative guidelines have been suggested in the milieu of some of the policy issues related to S&T and innovation that has triggered transformation and catalysed S&T developments in China[10].

India has declared 2010–2020 as a 'decade of innovation' with the objective of strengthening the S&T capacities and to enhance the GERD to 2% of its GDP[11,12]. The Government of India has approved the new Science and Technology Innovation Policy 2013 with the objective of: (i) positioning India among the top five global scientific powers by 2020 (by enhancing the global share of scientific publications to about 7.0%); (ii) establishing world-class infrastructure for R&D in select areas; (iii) making careers in science, research and innovation attractive for talented and bright minds; (iv) creating environment for enhanced private sector participation in R&D, technology development and innovation; (v) developing S&T-based high-risk innovation; (vi) increasing participation in international high-end science R&D projects[12]. The present study is carried out to delineate the impact of international collaboration on S&T output in terms of research papers published in co-authorship with international institutions and patents granted in collaboration with foreign co-inventors using China and India as a model.

Methodology

Data pertaining to science and engineering research papers published by Indian and Chinese scientists in co-authorship with international institutions have been taken from Science and Engineering Indicators-2014, National Science Foundation (NSF), USA. The number of patent applications filed by resident and non-resident applicants and patents granted was obtained from WIPO database. Patents granted by USPTO (US Patent and Trademark Office) to China and India in collaboration with foreign inventor(s) have been taken from the patent database of the Organization for Economic Cooperation and Development (OECD). Though there is a consistent increase in the number of papers published and patents granted with international cooperation to India and China, during the period 1997–2012, the data have been analysed on two time points, i.e. 1997 and 2012.

Comparative performance in co-authoring research papers with international institutions

The research papers published have been categorized as those published with domestic as well as with international institutions. In 1997, a total of 581,845 research papers were published by all the countries, including China and India in collaboration with domestic and international institutions which, with a growth of 46.4%, increased to 852,110 in 2012. Out of 581,845 research papers published in 1997, only 15.6% was published in co-authorship with international institutions and 84.4% was with domestic institutions, whereas in 2012, 25.0% of the total collaborative papers published was in collaboration with international institutions and 75.0% with domestic institutions (Table 1).

China published 10,721 research papers in science and engineering in 1997 in co-authorship with domestic institutions and 3,669 with international institutions compared to 8,654 with domestic institutions and 1,649 with international institutions respectively, by India. In 2012, China published 85,552 research papers co-authored with domestic institutions and 31,081 research papers co-authored with international institutions with a growth of 698% and 740% respectively, during 1997–2012. In contrast, India with a growth of 140% and 345% respectively, published 20,751 research papers with domestic institutions and 7,332 research papers with international institutions (Table 1). The analysis revealed an increase of 2.4- and 4.4-fold in co-authoring research papers with domestic and international institutions in 2012 over

Table 1. Number of science and engineering research papers co-authored with domestic institutions and with international institutions by India and China

Country	Number of science and engineering research papers co-authored						Percentage change in co-authored science and engineering research papers in 2012 over 1997		
	1997			2012					
	With domestic institutions	With international institutions	Total	With domestic institutions	With international institutions	Total	With domestic institutions	With international institutions	Total
World (including India and China)	490,978	90,867	581,845	640,269	211,841	852,110	30.4 (1.3)	133.1 (2.3)	46.4 (1.5)
China	10,721	3,699	14,420	85,552	31,081	116,633	698.0 (8.0)	740.3 (8.4)	708.8 (8.1)
India	8,654	1,649	10,303	20,751	7,332	28,083	139.8 (2.4)	344.6 (4.5)	172.6 (2.7)

Source: Science and Engineering Indicators 2014, National Science Foundation, USA.
Research papers with domestic institutions are counts of research papers with one or more institutional addresses all within the country, and research papers with international institutions are counts of research papers with one or more institutional addresses outside the country.
Figures in parenthesis represent the fold increase.

Table 2. Subject-wise number of research papers co-authored with domestic institutions and international institutions by India and China

Subject	Number of research papers co-authored							
	1997				2012			
	With domestic institutions		With international institutions		With domestic institutions		With international institutions	
	China	India	China	India	China	India	China	India
Engineering	1,508	1,038	526	153	15,479 (926)	3,398 (227)	4,973 (845)	1,010 (560)
Astronomy	88	89	59	80	406 (361)	243 (173)	503 (753)	244 (205)
Chemical science	2,503	2,246	451	271	21,953 (777)	6,081 (171)	4,461 (889)	1,477 (445)
Physical science	3,477	1,647	998	510	16,382 (371)	3,495 (112)	5,213 (422)	1,675 (228)
Geoscience	424	357	260	74	3,664 (764)	952 (167)	2,503 (863)	457 (518)
Mathematical science	347	102	154	32	1,855 (435)	183 (79)	914 (494)	113 (253)
Computer science	99	71	57	25	1,157 (1069)	120 (69)	814 (1328)	109 (336)
Agricultural science	34	217	57	41	1,755 (5062)	467 (115)	728 (1177)	112 (173)
Biological science	1,048	1,730	573	283	12,951 (1136)	3,626 (110)	5,981 (944)	1,192 (321)
Medical science	963	992	432	145	8,999 (834)	1,958 (97)	3,913 (806)	759 (423)
Psychology	55	16	38	7	297 (440)	32 (100)	357 (839)	34 (386)
Social science	175	149	94	28	654 (274)	196 (32)	721 (667)	150 (436)
Total	10,721	8,654	3,699	1,649	85,552 (698)	20,751 (140)	31,081 (740)	7,332 (345)

Figures in parenthesis represent percentage of growth in 2012 over 1997.

1997 respectively, by India in comparison to 8.0- and 8.4-fold increase achieved by China (Table 1).

Subject-wise research papers in co-authorship with international institutions

In 1997, India published maximum research papers in collaboration with international institutions in physical science (510), followed by biological science (283), chemical science (271), engineering (153), medical science (145), astronomy (80), geoscience (74), agricultural science (41), mathematical science (32), social science (28), computer science (25) and psychology (7) (Table 2). Similarly, China published maximum research papers with international institutions in physical science (998), followed by biological science (573), engineering (526), chemical science (451), medical science (432), geoscience (260), mathematical science (154), social science (94), astronomy (59), agricultural science and computer science (57 each) and psychology (38) (Table 2).

In 2012, China published maximum research papers in collaboration with international institutions in biological science (5981), followed by physical science (5213), engineering (4973), chemical science (4461), medical science (3913), geoscience (2503), mathematical science (914), computer science (814), agricultural science (728), social science (721), astronomy (503) and psychology (357). In contrast, India published maximum research papers in collaboration with international institutions in

Table 3. Distribution of resident and non-resident patents filed and patents granted during 1997–2012

	Patent applications filed						Patents granted					
	World (including China and India)		China		India		World (including China and India)		China		India	
Year	Resident	Non-resident	Resident	Non-resident	Resident	Non-resident	Resident	Non-resident	Resident	Non-resident	Resident	Non-resident
1997	737,100 (63.4)	426,000 (36.6)	12,672 (51.2)	12,102 (48.8)	1,926 (19.0)	8,229 (81.0)	318,800 (64.0)	179,100 (36.0)	1,532 (43.8)	1,962 (56.2)	546 (32.0)	1,161 (68.0)
2012	1,513,100 (64.5)	834,300 (35.5)	535,313 (82.0)	117,464 (18.0)	9,553 (21.7)	34,402 (78.3)	694,200 (61.2)	439,600 (38.8)	143,808 (66.2)	73,297 (33.8)	722 (16.7)	3,606 (83.3)

Source: Statistical Country Profile; http://www.wipo.int/ipstats/en/statistics/country_profile; http://www.wipo.int/ipstats/en/statistics/country_profile/countries/in.htm and http://www.wipo.int/ipstats/en/statistics/country_profile/countries/cn.htm
Resident application: An application filed with an IP office by an applicant residing in the country in which that country has jurisdiction.
Non-resident application: An application filed with a patent office of a given country by an applicant residing in another country.
Figures in parenthesis represent percentage of total.

physical science (1675), followed by chemical science (1477), biological science (1192), engineering (1010), medical science (759), geoscience (457), astronomy (244), social science (150), mathematical science (113), agricultural science (112), computer science (109) and psychology (34) (Table 2).

The percentage growth in terms of research papers co-authored in 2012 over 1997 by India with international institutions compared to domestic institutions was higher in all areas, whereas in the case of China, the percentage growth of research papers co-authored with international institutions during the same period in comparison to domestic institutions was more or less the same. Though research papers co-authored by India in collaboration with international institutions have grown at a faster pace in all subject areas compared to research papers co-authored with domestic institutions, the absolute number of research papers co-authored with international and domestic institutions by India as well as their growth rate was much lower than China (Table 2).

Comparative performance in patent applications filing and patents granted

Patents are one of the important indicators of innovation, linked with economy. The Indian patent office filed 10,155 patent applications in 1997 and 43,955 in 2012, with an increase of 332% in comparison to 2534% of China. During the period 1997–2012, India witnessed an average annual growth of 13.6% and 15.7% respectively, in patent applications filing and patents granted in contrast to 25.7% and 33.2% in China. Further, in comparison to China, the patent applications from individuals and universities in India are very low[13]. China filed 825,000 patent applications in 2013 with 26.3% yearly growth and surpassed both USA and Japan in filing patent applications[12]. Greater emphasis has been laid by individuals and enterprises to increase the number of patent applications for intellectual property protection[13,14].

During 2010–11, CSIR was the leading organization amongst the scientific and research development organizations in India for PCT patent applicants with 183 patent applications, followed by DRDO (59), whereas amongst the academic institutions, the Indian Institute of Technology, Mumbai with 58 patent applications was the leading institute followed by the Indian Institute of Science, Bengaluru (38)[13,15].

The relative proportion of patent applications filed by residents and non-residents in 1997 indicates that only 19% of total applications filed in India pertained to residents compared to 51% in China. In 2012, the share of resident applications filed in India remained more or less the same (21.7%), whereas a significant increase of 31% (over 1997) has been observed in case of China. The share of patents granted to residents in India during 1997 was 32%, which reduced to 16.7% in 2012. On the contrary, the share of resident applicants granted patents from China was 43.8% in 1997, which increased to 66.2% in 2012 (Table 3). The share of China in total patents filed and patents granted in the world in 1997 was 2.1% and 0.7% respectively, in comparison to 0.8% and 0.3% respectively, in case of India. In 2012, China's share in patents filed and granted rose to 27.8% and 19.1% respectively, in comparison to 2.0% and 0.4% respectively, in the case of India.

India and China attained significant growth during the period 1997–2012 in terms of patents granted by USPTO in collaboration with foreign inventors. A total of 11.1% and 22.6% patents have been granted by USPTO to the countries of the world in collaboration with foreign inventors during 1997 and 2012 respectively (Table 4). Out of the total patents granted by USPTO to all countries of the world in collaboration with foreign inventors during 1997 and 2012, the share of India increased from 0.6% in 1997 to 7.4% in 2012, whereas during the same

Table 4. USPTO patents granted to India and China in cooperation with foreign inventors

Patents granted	Total patents granted		Patents with foreign co-inventor(s)		Foreign ownership of domestic inventions and domestic ownership of inventions made abroad	
	1997	2012	1997	2012	1997	2012
World	111,995	253,123	–	–	–	–
Patents granted with international cooperation in the world	12,480	57,284	3,866	17,209	8,614	40,075
Patent granted with international cooperation to China	117	7,839	44	1,886	73	5,953
Patent granted with international cooperation to India	70	4,236	32	1,128	38	3,108
Percentage of patents granted with international cooperation of total patents granted in the world	11.1	22.6	3.5	6.8	7.7	15.8
Percentage of patents granted with international cooperation in China of total patents granted with international cooperation in the world	0.94	13.68	1.14	10.96	0.85	14.85
Percentage of patents granted with international cooperation in India of total patents granted with international cooperation in the world	0.56	7.39	0.83	6.55	0.44	7.76

period, the share of China increased from 0.9% to 13.7% (Table 4).

Conclusion

Science and engineering research publications from India in co-authorship with international institutions increased 4.5-fold in comparison to 8.4-fold increase in the case of China during the period 1997–2012. Absolute number of research papers co-authored with international institutions and domestic institutions was 4.2 and 4.1 times higher respectively, in the case of China in comparison to India during the period.

Maximum research papers in collaboration with international institutions published from India in 2012 were in the area of physical science, followed by chemical science, biological science, engineering, medical science, etc., whereas China published maximum research papers with international collaboration in the area of biological science, followed by physical science, engineering, chemical science, medical science, etc. `

The share of patent applications filed by residents in India in 2012 was only 21.7% compared to 82.0% by residents in China, whereas in terms of patents granted, the share of resident applicants in India was 16.7% compared to 66.2% in China. Further, the share of India to patents granted by USPTO to all countries of the world in collaboration with foreign inventors increased from 0.56% in 1997 to 7.39% in 2012, whereas the share of China increased from 0.94% to 13.68% during the same period. Thus, the significant increase in research papers published in collaboration with international institutions and patents granted in collaboration with foreign inventors by China in comparison to India indicates that China has harnessed the fruits of its international cooperation in S&T to its advantage. An increase in international footprints through the joint research programmes, especially with the NRI community may help India to further increase its S&T output and broaden its S&T knowledge-base in emerging, critical and thrust areas.

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