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Comparative analysis of scientific output of BRIC countries

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Based on data for the period 1980-2009 downloaded from the Scopus database, an attempt is made to analyse the growth of publication share in BRIC countries (Brazil, Russia, India and China) vis-à-vis the United States in terms of world publications output and emerging areas and disciplines during 1980–2009. Also, comparative estimates are made using a competition model to analyse the emerging patterns of scientific publication in the BRIC region. Results indicate that China may be an emerging leader in scientific publication followed by India among the BRIC countries.

Introduction

It is well known that a country's scientific capability plays a key role in its economic progress that fosters advancements in the scientific and technological (S&T) research. Today, the European Union (EU) and United States publish the larger share of the world's total scientific publications. In the recent years, the scientific publication output in Latin America, South East Asia, North Africa, Eastern Europe and Sub-Saharan Africa increased but Russia's publication output declined during 2009. This attracted the attention of scholars and policymakers' to analyse publication growth in Russia and more particularly in emerging economies like Brazil, Russia, India and China commonly known as BRIC region. The share of research contributions of BRIC countries to the world output is comparatively low but within the BRIC region, China has been a major contributor.

BRIC countries have been investing heavily in developing infrastructure for research and development (R&D) in different fields of S&T, as well as in the frontier areas such as atomic energy, space sciences, electronics, telecommunications, and more recently in biotechnology. China's R&D spending was highest (1.5% of gross domestic product [GDP]) in 2007 followed by Russian Federation (1.1%) and Brazil (1.0%). India's R&D expenditure (0.8%) was lowest among the BRIC countries and is likely to increase to 2 percent in the next five years. Thus China, Brazil and Russia are investing heavily in the R&D to improve their scientific output. But available statistics show that scientific output in BRIC countries is not comparable as in the developed countries except China, which has shown a rapid increase in its publication output 2008 and 2009.

R&D expenditure and personnel in the BRIC region

Policies in emerging economies are directed to build up countries' educational and academic infrastructure to support R&D capabilities. Consequently, a rapid economic growth over the past decade or more is observed among the Asian (National Science Foundation, 2007)[1] economies, next to Japan. Further, BRIC countries are projected to be the fastest-growing economies in the world. The BRIC governments have declared education and S&T to be a strategic engine of sustainable economic development. Therefore, BRIC governments are boosting their R&D investments and China, followed by India, has become an important player in research output. China was the third largest R&D-performing country in 2003, behind the United States and Japan and has increased the percentage of its GDP spent on R&D. Among the BRIC countries, the gross domestic expenditure on R&D (Figure 1) as a percentage of GDP was highest in China (1.5%), followed by Russian Federation (1.1%), Brazil (1.0%) and India (0.8%) in 2007. The share of world R&D expenditure (GERD) by China was 9.2 percent, followed by India

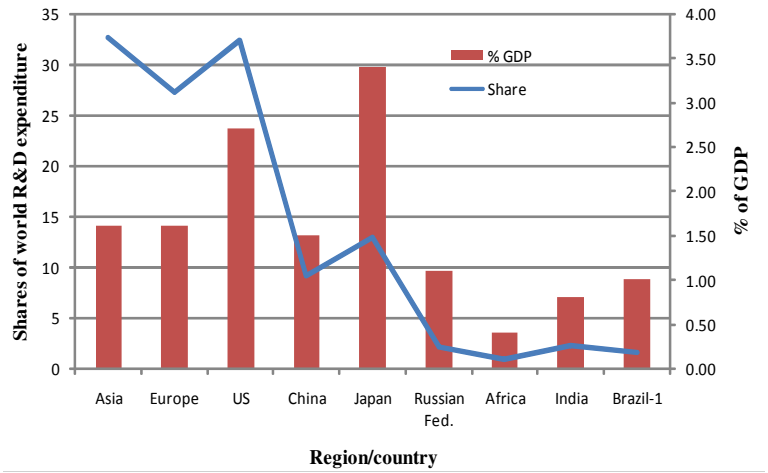

Fig. 1—R&D investment as % of GDP and shares of world expenditure (2007)
Note: Brazil-1 indicates figures for 2006

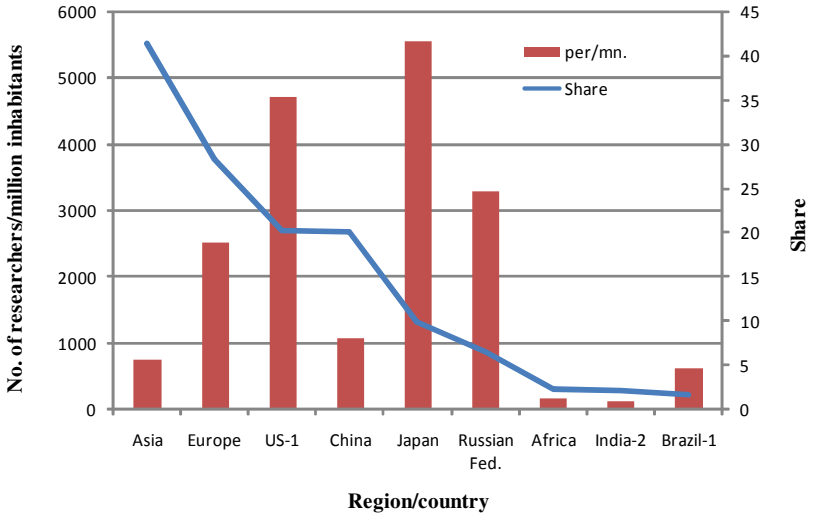

Fig. 2—Shares of world researchers & per million inhabitants (2007
Note: Brazil-1 indicates figures for 2006; India-2 indicates figures for 2005 & US-1 indicates figures for 2006

(2.2%), Russian Federation (2.0%) and Brazil (1.6%), while the United States and Asia's share were 32.9 percent and 32.7 percent, respectively, in 2007 (UNESCO, 2010)[2].

Similarly, R&D human resource was also observed to be skewed, as Russia topped the most researchers per million inhabitants in the BRIC countries in 2007. There were 3,292 researchers per million inhabitants in the Russian Federation, 1,071 in China, 625 in Brazil (2006) and 136 in India (2005). In 2007, the total number of researchers in China was 1423.4 thousand, followed by Russia (469.1 thousand), India (154.8 thousand) and Brazil (124.9 thousand). The world average of researchers per million inhabitants was 1,063 whereas there were 742 and 4,707 researchers in Asia and United States, respectively, for the same period. Also, share of world researchers in China was 20.1 percent, comparable with United States (20.3%) in 2007; it was 6.6 percent for Russia, followed by India (2.2%), Brazil (1.1%), while Asian average was 41.4 percent (Figure 2). It may be argued that China is emerging in R&D activities in the BRIC region although Russia comprises highest number of

researchers per million population. This is also supported by Gaillard[3] who emphasised that R&D has increased rapidly in China over the last decade. On the other hand data indicates that Brazil has the least R&D intensity. However, BRIC is emerging as the largest pool of R&D personnel which may further rise due to rapid growth of enrolments in tertiary education, particularly in China and India.

Earlier studies signify that North America and Europe dominate the number of scientific publications produced annually[4], which resulted in inequalities in research between developed and developing countries. This was also highlighted by Kofi Annan (2003)[5], the former Secretary-General of the United Nations who argued that to meet the challenges of building bridges across these gaps, the world scientific community should come closer to each other. He further, underlined the importance of reducing the inequalities in science between developed and developing countries. Studies also show that disparity existed in scientific output between developing and developed countries, which obstructs the development process in developing countries[6-8]. According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO) the developed countries accounted for some 84 percent of the global investment in scientific research and development, had approximately 72 percent of the world researchers, and produced larger share of scientific and technical publications as reflrected from Science Citation Index (SCI). North America and Europe accounted nearly 36 percent and 37 percent share of scientific publications produced worldwide (UNESCO, 2001)[9]. Evidently developing countries are lagging behind in publication output despite several measures initiated, particularly by the BRIC governments.

Objectives of the study

- To analyse the growth of publication share in BRIC countries vis-à-vis the United States in terms of world publications output and emerging areas and disciplines during 1980–2009; and

- To present comparative estimates of scientific publication in the BRIC region using a competition model.

Methodology

The publications data (from 1981 to 2009) for the study pertaining to scientific publication were collected and computed from the SCOPUS[10] database. The SCOPUS database is an online international multidisciplinary database indexing over 18,000 international peer-reviewed journals and conference proceedings etc. However, the Scopus covers only a fraction of Indian scientific journals (247 at present) compared to a total of 1167 journals covered by 14 other databases taken together. Hence, the figures given for India are unlikely to provide the real picture.

The sources of data extraction like journal or conference/seminar proceeding were considered and subjects nomenclature were taken as defined in the database. The database was accessed during August/September 2010.

For making projections Kumar-Rai Model[11] was used which is represented mathematically below:

$$\log\left(\frac{f}{1-f}\right) = a + b\sinh^{-1} t \qquad \ldots(1)$$

where *'f'* is the share of the emerging or competitive process, (*1-f*) represents remaining share of the process at any time *'t'*, and a, b are model parameters. The model is based on the following assumptions:

- An emerging process can be considered as competitive substitutions of one method or process satisfying the need for another.

- If a substitution has progressed as far as a few per cent, then it will proceed to completion or saturation level.

- The rate of fractional substitution of new/emerging process for old is proportional to the remaining amount of the old left to be substituted.

Assuming that the competition between different processes or methods is similar to competing technologies and behave in the similar manner, technology substitution model is applied for the study.

Analysis

Research output of BRIC countries

Data on publication output are valuable sources of information, which may have inconsistency because different databases have different methodologies and sources that cover a wide range of journals and published articles. However, it is a sound and valid marker of performance of a country's scientific and research activities. Table 1 gives the percentage share of global publications output the different counties. It is apparent that publication output is skewed towards China after 1994, while Russia's progression seems relatively slow, which is obtained by calculating the nation's annual volume of publication output. Also, Russia's relative publication growth against three of its counterparts in the BRIC countries-India and Brazil, and China-exhibited decline toward the end of the 2009 whereas publication output for India rises and for Brazil it grows slightly. China has a sharp rise that dwarfs other BRIC nations and may catch up with United States in the near future. It is significant to mention that China produced ≈ 13 percent papers of the total world publications, second to the United States, which has ≈ 24 percent share of the global publication share. China was followed by India (2.8%), Russia (1.6%) and Brazil (2.0%) and the total BRIC publication share was nearly 19 percent of the global publication in 2009.

Over the five-year period 2005-2009, Russia produced roughly 164,126 papers in all fields of science, accounting for approximately 1.73 percent of the world's papers published in journals indexed by SCOPUS. For comparison, this is more than Brazil (156,619 papers, 1.65 percent of world) but less than India (234,123 papers, 2.47%) and far less than China (1050430 papers, 11.07%). But United States produced roughly 1,893,222 accounting ≈19.94 percent of the world output. However, in the year 2009, India (2.84%), Brazil (1.97%), China (13.71%) and United States (20.32%) registered a rise in the publications output over the five year period 2005-2009, while Russia's output declined (1.64%).

Emerging priorities in research areas

Changes are taking place in scientific research activities and priorities of thrust areas, which result in a shift in the production of scientific publication in developing countries. According to Hassan (2010)[12] there was rapid and substantial growth in the number of scientific publications emanating from the developing world and the trends are accelerating. Further, he underlined that China, for example, secured 13th place in world rankings for articles published in the peer-reviewed international journals devoted to science, medicine and engineering between 1981 and 1994. China's scientists accounted for just 0.9 percent of the total number of articles worldwide, but it captured 8th place, as its global share of publications rose to 3.6 percent in 2000. By 2007, China jumped to second place in global rankings, trailing only the United States, as its global share of publications reached 7.6 percent. The percentage of publications in countries beyond the top-eight performers (the United States, China, Japan,

Table 1—Comparative share of publication for BRIC and USA

Year	India	Brazil	China	Russia	USA	BRIC
1981	1.3	0.3	0.2	0.6	20.0	2.4
1982	1.2	0.3	0.2	0.5	19.0	2.2
1983	1.0	0.2	0.2	0.5	17.8	1.9
1984	1.0	0.2	0.3	0.5	19.0	2.0
1985	1.0	0.2	0.3	0.5	19.7	2.0
1986	1.0	0.2	0.4	0.5	19.2	2.1
1987	1.1	0.2	0.4	0.5	19.2	2.2
1988	1.3	0.3	0.8	1.0	22.1	3.4
1989	1.4	0.3	0.9	1.1	23.8	3.7
1990	1.3	0.3	0.9	1.0	25.2	3.5
1991	1.3	0.4	1.0	1.7	25.2	4.4
1992	1.3	0.4	1.1	1.5	25.2	4.3
1993	1.3	0.4	1.7	1.6	26.9	5.0
1994	1.4	0.5	1.5	1.6	27.0	5.0
1995	1.3	0.5	1.7	1.6	26.5	5.1
1996	1.8	0.8	2.4	2.7	28.3	7.7
1997	1.8	0.9	2.7	2.7	27.5	8.1
1998	1.9	1.0	3.1	2.7	27.3	8.7
1999	2.0	1.1	3.3	2.6	26.9	9.0
2000	1.9	1.1	3.6	2.5	25.9	9.1
2001	1.8	1.0	4.4	2.3	23.5	9.5
2002	1.9	1.2	4.2	2.2	23.3	9.5
2003	2.1	1.3	4.9	2.2	23.8	10.5
2004	2.0	1.3	6.5	2.0	20.4	11.8
2005	2.1	1.3	8.8	2.0	19.8	14.2
2006	2.3	1.5	9.8	1.7	20.1	15.3
2007	2.4	1.6	10.6	1.7	19.9	16.3
2008	2.6	1.8	12.0	1.7	19.5	18.1
2009	2.8	2.0	13.7	1.6	20.3	20.1

Germany, the United Kingdom, France, Italy and Canada) more than doubled from 18.4 percent to 37.5 percent between 2000 and 2007. China accounted for nearly one-third of all publications in science, engineering and medicine in the developing world. Moreover, 11 other developing countries or countries with emerging economies (led by India, South Korea, Brazil, Taiwan and Turkey) were responsible for more than 85 percent of the publications in the developing countries in 2007. It describes the rise of science in developing countries, particularly in BRIC region, as over the last decade the scientific output was boosted in China and India. Additionally, to keep pace with the world output and bridging the gap between developing and developed world in the scientific output, the BRIC countries are performing better in many disciplines.

It was observed that the research priorities, with a few exceptions, are comparable in the BRIC countries vis-a-vis the United States. It is noticeable that Brazil, Russia, India and the United States have first or following priorities in natural or life sciences, whereas in China the highest numbers of papers were published in engineering in 2009, which constitutes nearly 20 percent of the total research papers followed by physics and astronomy (P&A) (≈10%), material science (Mat Sci) (≈10%) and chemistry (≈7%). The share of computer science increased significantly from about 4 percent in 2001 to 14 percent in the year 2009. However, the share of publication in medicine, biochemistry, genetics and molecular biology (BG&M Bio) and mathematics shows increasing trends. In the case of India, the highest number of papers were published in medicine (≈12%) in 2009, followed by chemistry (≈10%), agriculture and biological sciences (A&B Sci) (≈6%) and physics and astronomy (P&A) (≈9%). The share of publication in chemistry (≈11%), agriculture and biological sciences (≈10%) and physics and astronomy (≈10%) indicated declining patterns as compared with 2001. On the other hand, the share of publications in engineering, material science and pharmacology, toxicology and pharmaceutics increased over the last decade. The share of publication in engineering increased from 8.3 percent to 10.7 percent during 2001 to 2009, followed by material science (8.2% to 8.6%) and pharmacology, toxicology and pharmaceutics (4.1% to 5.4%) for the same time span.

Similarly, in the case of Brazil, medicine, physics & astronomy and agriculture & biological sciences were the most productive disciplines. However, the share of publications in medicine and agriculture & biological sciences grew marginally. The share of publications in medicine increased from 17.2 percent in 2001 to 18.2 percent in 2009 and agriculture & biological sciences enhanced from 10.4 percent to 11.8 percent during the same period. The share of publications in other disciplines was observed to be declining. The share of publications in mathematics, chemical engineering, agriculture & biological sciences and medicine improved in Russia during 2001 to 2009. The share of publications in mathematics increased from 4.7 percent to 6.9 percent, chemical engineering from 3.7 percent to 3.9 percent, agriculture & biological sciences from 2.7 percent to 3.4 percent and medicine from 2.2 percent to 2.9 percent during 2001-2009. Moreover, physics & astronomy, chemistry, material science, engineering, earth and planetary science were the most productive subjects. However, in the case of the United States, the share of publications in engineering increased from 9.3 percent to 9.5 percent and in material science increased from 3.3 percent to 4.3 percent during 2001-2009, while other subjects show either constant share or marginal increase for the same period. On the contrary, medicine, biochemistry, genetics & molecular biology (BG&M Biology), engineering, physics & astronomy (P&A) and agriculture & biological sciences were the highest productive subjects, comprising 51.3 percent in total number of publications in 2009. The top 5 emerging subjects in the BRIC countries vis-a-vis the United States are illustrated from Figures 3 to 7 for the period 2001-2009.

Projected publications output for 2011-2025

Publication data during 1981-2009 for the BRIC countries and the United States were analysed using competition models as discussed above. The process of competition tends to proceed with a constant percentage annual growth increment or exponentially in the early years and follow a logistic (S-shaped) curve. A nonlinear least square method was applied to estimate the model parameters (Table 2) using SYSTAT[13] package (SYSTAT Inc., Evanston, IL). Model parameters were obtained by quasi–Newton

iterative technique. Using values of the parameters projections were made for the publications up to the year 2025 AD, which are depicted in Table 3.

Projections indicate that publication productivity of the United States is saturating and there could be a significant increase in the publication share of the BRIC region in the future. If the present trends continue, then BRIC may surpass the United States by the year 2013 and China's contribution will be the highest, followed by India, Brazil, and Russia. From the Figure 3-7, it is evident that Brazil, India and Russia have been producing reasonably increasing number of publications which may follow the same pattern in future. By 2020, BRIC countries may be the largest producer of the publications comprising nearly 37 percent of the world publication output. This may further increase to 45 percent in 2025, while the United States may face stagnation during the period. Among BRIC countries, China's share is expected to be nearly 18 percent and 22 percent for 2020 and 2025 respectively. India is expected to be second to China, with 4 percent and 4.5 percent followed by Brazil (4% and 4.4%) and Russia (3.5% and 4%) for the year 2020 and 2025 respectively.

Discussions

China's research output is growing rapidly. Science education seems to be making a difference for China's continued ascent as compared to the other BRIC countries. According to the Times Higher Education World University Rankings (TSL Education, 2010)[14] Brazil, Russia, and India have no institutions in the top 200 list in 2010-11, but China has its presence with 5 universities/institutions on this list, which also indicates China's entry into the global higher educational elite club. Significantly, the United States has 69 universities/institutions on the list. However, the R&D spending of Russia is more than Brazil and India, but publications output could not increase because of the uncertainty after collapse of

Table 2—Parameter estimates for different countries

Sl. no.	Country/Region	Parameters			
		A	b	Mean Square Error	Corrected R^2
1.	Brazil	-6.324	0.084	1.372	0.962
2.	China	-6.367	0.157	3.882	0.991
3.	India	-4.685	0.036	0.824	0.918
4.	Russia	-4.684	0.034	0.792	0.824
5.	BRIC	-4.217	0.096	11.979	0.984
6.	USA	-1.265	0.003	4.566	0.871

Table 3—Comparative projection of publications for BRIC and USA (%)

Year	India	Brazil	China	Russia	USA	BRIC
2011	2.8	2.3	14.2	2.5	23.7	22.3
2012	2.9	2.4	14.7	2.5	23.8	23.1
2013	3.0	2.5	15.1	2.7	23.9	24.0
2014	3.1	2.7	15.3	2.8	23.9	25.1
2015	3.2	3.0	15.9	3.0	24.0	26.9
2016	3.3	3.2	16.4	3.1	24.0	28.4
2017	3.4	3.4	16.8	3.1	24.1	30.5
2018	3.6	3.6	17.2	3.2	24.1	32.9
2019	3.7	3.8	17.7	3.4	24.2	34.0
2020	3.8	3.9	18.1	3.5	24.3	36.3
2021	3.9	4.1	18.5	3.5	24.3	38.0
2022	4.1	4.2	20.1	3.6	24.4	39.7
2023	4.2	4.2	20.5	3.7	24.4	42.1
2024	4.4	4.3	21.0	3.9	24.5	43.4
2025	4.5	4.4	21.9	3.9	24.6	44.7

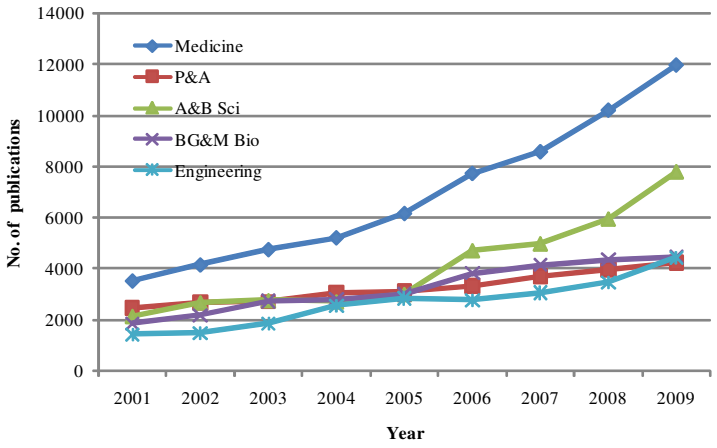

Fig. 3—Publication productivity in emerging areas in Brazil

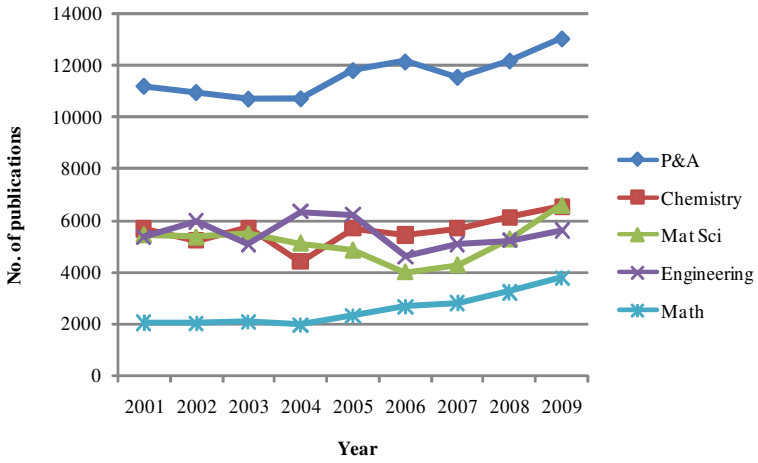

Fig. 4—Publication productivity in emerging areas in Russia

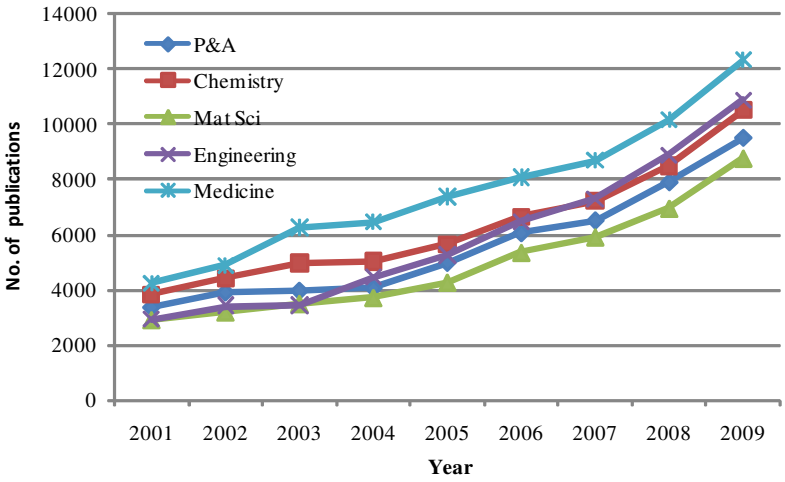

Fig. 5—Publication productivity in emerging areas in India

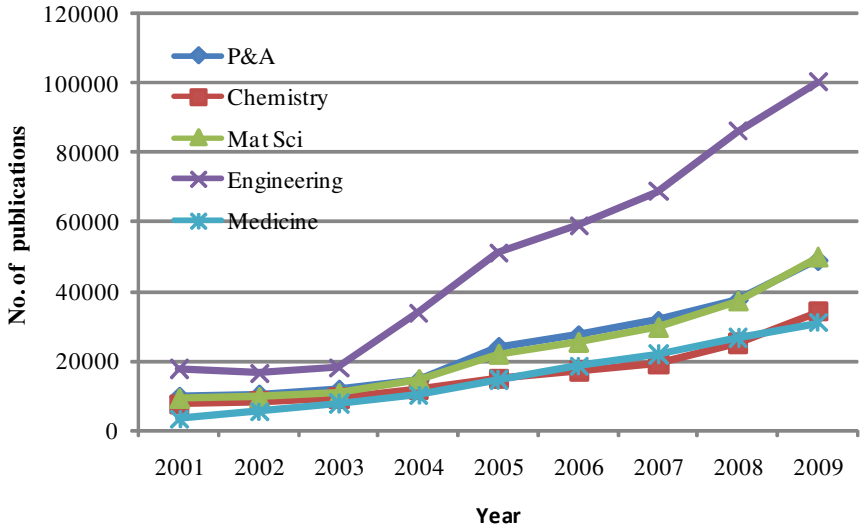

Fig. 6—Publication productivity in emerging areas in China

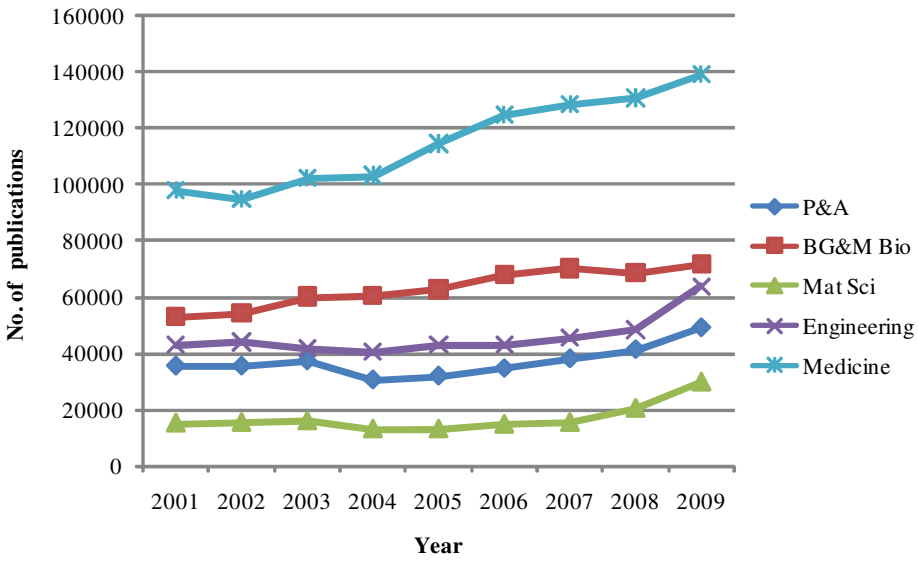

Fig. 7—Publication productivity in emerging areas in USA

the Russian federation. But now two theories have emerged: firstly, the quantitative reduction in the human capital among scientists and its demographic degradation[15] and, secondly, Russian scientists being unlikely to use international mobility as the main way of integrating the Russian science into the global scientific community. Consequently, Russia lags behind in foreign co-authored publications as compared with the most of scientifically advanced countries. They communicate mainly with their colleagues within Russia, while the number of co-authored papers has grown in India, China and the United States.

The Government of India spending on research was 0.9 per cent of gross domestic product in 2009; which is expected to rise to 1.2 per cent by 2012. But, Indian

university system is traditional and many state universities are underfunded and face shortage of academic staff. This may be a critical issue in India's higher education and research. Therefore, the Ministry Human Resource Development (MHRD) is trying to reunite research and teaching in universities to create a number of world-class, research-led institutions. As a result, the higher education sector is rapidly growing in India. The projections suggest that BRIC countries may lead in scientific output in the future. This supports the Grueber's[16] argument, who advocated the leadership of China and India not only in BRIC countries but also across other Asian countries in the area of science and technology. The publication shares of Brazil and Russia, to the world's total scientific publications, is also expected to increase. Consequently, the BRIC countries are expected to catch-up its position the most publishing countries in future which indicates a shift in the nature of knowledge accumulation from developed countries to developing countries.

Conclusion

The bibliometric indicators are frequently used and suitable markers of scientific activities expressing what kind of research is being performed in different countries and institutions. Empirical data illustrates that the developing countries contribution to world scientific publication is not comparable with the developed countries. However, recent trends provide a positive swing towards the emerging countries particularly BRIC countries. It is evident from the analysis that China and India are increasing their R&D output and if the current trends persist, China may compete with US in terms of scientific publications. India is expected to follow China and Brazil is expected to raise its publication output while scientific publications output of Russia is also expected to increase as compared to the existing trends. Further, BRIC countries may emerge as the global leader in R&D output in future.

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