Scientific collaboration between BRICS Countries.

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Abstract: The five BRICS Countries (Brazil, Russia, India, China and South Africa) are among the most important developing Countries. They are joined in an association to foster mutual development. The present article analyses scientific collaborations between the five Countries using coautorhips of scientific products obtained from Scopus® database. Besides absolute values, Salton's and Jaccard indexes are used to measure the strength of inter-BRIC collaborations, as well as their evolution. The collaboration in scientific sub-areas is also measured. Result show some heterogeneity among the different bilateral collaborations. Most of them have changed pace in years 2007-2009, growing in intensity. Analysis of research area show that, also in this case, there is heterogeneity. At the end of the work the results are discussed with the aid of BRICS official documents in order to understand the relations between policy issues and the obtained results.

Keywords: BRICS Countries; International Coautorship; Scientific Collaboration; Salton's index; Jaccard index.

1. Introduction

World geo-political equilibrium has been rapidly changing at the end of the 20th Century and at the beginning of the new Millennium. Among other issues is for instance worthwhile to be examined the new role assumed by emerging Countries. Their economic weight, as well as their scientific and technological production, are growing steadily. This has happened – at least partly – at the expense of historical actors such as the U.S.A. and the European Countries.

Among such emerging Countries the role of BRICS – Brazil, Russia, India, China and South Africa – is particularly relevant. In fact, these five Countries are among the major emerging economies, distinguished by their fast (though heterogeneous[1]) growth. Moreover – and what is at the starting point of the present work – they are joined in an Association of Countries. The acronym BRIC, indicating the first 4 Countries in the list, was coined at the beginning of the 2000s (see for instance Wilson & Purushothaman, 2003). BRIC Countries subsequently did create an Association, and since 2009 their leaders meet regularly in formal summits, held in one of the Countries. Then, subsequently, in 2010 South Africa did enter in the Association. The aim of BRICS Association is mutual collaboration in order to improve the economies of the member Countries.

[1] See Biggerman & Fam (2011) for a discussion on inequalities in BRIC Countries, as well as on their growing importance.

Given these facts, exploring their features, and in particular their relations, is a relevant topic. Among the various topics, that of scientific research deserves deepening. It is well known in fact that the production of new scientific knowledge and of new technologies is an important driver of innovation and thus of development. The present work aims at exploring scientific production of the five BRICS. In particular it tackles the topic of scientific collaborations between BRICS Countries. The study is conducted with the aid of bibliometric indicators, and tries to respond to some research questions: how strong are the ties in scientific collaboration between BRICS Countries? Are there specific research topics presenting stronger collaboration? Is scientific collaboration an instrument for BRICS to foster their collaboration towards their aims? Or, conversely, did the creation of BRICS foster scientific collaboration between the five Countries?

Bilateral coauthorships are the instrument used to measure collaborations. Some authors dispute whether coauthorship alone is able to describe scientific collaboration (see for instance Lundberg *et al.*, 2006, and Laudel, 2002). Nevertheless several other authors state their reliability. For instance Franceschet & Costantini, 2010, p. 541, affirm that "Co-authorship in publications is widely considered as a reliable proxy for scientific collaboration" (see also citations therein). Also Glänzel *et al.* (1999) exploit coautorship as an index of international cooperation. Thus coautorships have been deemed a suitable instrument for the present analysis.

Responding to the above defined research questions is also relevant in terms of policy, due to the above described importance of scientific research for the Economic growth. Finally, as also literature overview shows, there is a lack of knowledge on the specific topic, which has not been tackled as far as now to my knowledge.

The present work is organized as follow. Next section contains a literature overview. Section 3 describes data mining strategy, while section 4 presents the main activity: data analysis and results. Finally, section 5 synthetically discusses the obtained results and enucleates the conclusions responding to the above presented research questions.

2. Literature overview

2.1 The BRIC(S) Countries in Research literature

Some recent studies describe the features of Economics and Innovation of BRICS (or BRIC) Countries. For instance Tseng (2009) uses patent data to show the innovative features of the four BRIC. Chan & Daim (2012), on their side, perform a case study analysis on technology foresight activities in the four Countries, identifying the most relevant issues in the field for emerging Countries. Their study shows that, as conditions are rapidly evolving, "a dynamic thinking is very necessary. Technology foresight studies should be adjusted in a timely manner to deal with economic and social changes" (p. 629). Finally, Vikas (2011) describes industrial relations inside the four BRIC, also showing their historical path and comparing the four Countries.

The emergence of South Africa has been described by Yanacopulos (2013) under the double profile of internal development and external aspirations, there comprising its status in BRICS.

The works of Manaperi (2014), Pant (2013) and Singh (2013) offer a wide introduction to the strengths and weaknesses of BRICS. Singh (2013) presents the strengths of the five Countries, and their chances for a "niche role in global financial governance" (p. 394). Nevertheless, BRICS have also "generated an expectation revolution among developing Countries that need to be fulfilled" (p. 397). Problems for the future development of the group have been highlighted in particular by Pant (2013), with particular regard to the peculiar role of China. Finally, Manaperi (2014) performs a more punctual analysis on the relations between inflation and economic growth, pointing out a different behaviour of Indian economy with respect to the others.

The reviewed papers, and in particular the most recent ones, present together with the strengths of the group some problematic issues of their relations. As defined in the research questions, one of the aims of the present work is to understand whether scientific collaborations might be, instead, a driver of mutual cooperation and growth between the five BRICS.

2.2 Studies on International Collaborations in Research activities

The stream of literature describing the study and measurement of international collaboration in science is in itself rather vast and multifaceted. Thus this section will present only some of the most relevant contributions to the topic; both earlier and more recent contributions are discussed.

Both multinational/multilateral and bilateral collaborations have been studied. The latter topic is obviously the most interesting in the framework of this article, as BRICS bilateral collaborations are described. Thus it will be taken in consideration in the present section[2]. Moreover articles might either deal more strictly with methodological subjects or focus instead on specific collaboration cases.

In the first group of works an earlier contribution by Luukkonen *et al.* (1993) did address the measurement of international collaboration in science. In order to describe collaboration authors exploited two indicators, Jaccard similarity coefficient and Salton's index. These indexes are used because, as authors affirm, "If we want to go beyond absolute differences in Country sizes and estimate 'propensities' or 'intensities' of collaboration, we have to develop measures which take size into account" (p. 21).

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[2] See for instance Nederhof & Moed (1993) de Lange & Glänzel (1997), Glänzel & deLange (1997) and Glänzel & de Lange (2002) for the modelling and measurement of multilateral collaborations.

More recently Lancho-Barrantes *et al.* (2013) study the effect of collaborations on citation impact. Their findings show a positive effect of collaboration towards citations received by a Country's articles. Different disciplines show different trends. Gazni *et al.* (2012) do instead perform a global mapping of scientific collaborations. Their database encompasses more than 13 million articles from ISI-Web of Science, and the performed analysis shows an increase of international collaborations from 14% in 2000 to 18% in 2009. Authors map the World network of collaborations, and also assess the lack of uniformity across disciplines: life sciences show the highest rate of collaboration, whereas social sciences have the lowest (p. 332).

Finally, a complete review of similarity measures has been performed by van Eck & Waltman (2009). According to their study, among the most popular direct similarity measures are the cosine (Salton's) and Jaccard index. These two indexes are exploited in the present work.

To the second group belong for instance the work of Glänzel *et al.* (1999) who also use Salton's index in their study on EU Countries. In their work they also state that "the basic indicator of international scientific collaboration is the number of internationally co-authored publications" (p. 187). Their article presents also mappings of co-authorship networks between Countries, as well as data on citation attractiveness. Their results, based on papers published between 1985 and 1995, show "the dramatic rise of Russian co-publication share with Western countries after 1990" (p. 196). More in general they show the "ever growing importance of the EU as scientific collaboration partner of both advanced and developing countries" (p. 201).

Narváez-Berthelemot *et al.* (1999) describe instead scientific collaboration in the Latin American Mercosur Countries (Argentina, Brazil, Paraguay and Uruguay). The pattern of collaboration between the four Countries was rather uneven; nevertheless no normalization of coauthorships has been performed. Gupta *et al.* (2002) use a similar approach (measures based on the count of co-authored articles) in their analysis of the collaboration of India with South-East Asian Countries. The collaboration with Malaysia results being the strongest, in particular in Chemical sciences. He (2009) study collaborations of China with the G7 Countries. Data show a growth in collaboration with all seven Countries in parallel with the growth in the number of Chinese publications. A wider overview on Chinese collaborations is instead offered by Niu & Qiu (2013). The analysis of a dataset extracted from Web of Science shows an increase of international collaborations; interestingly "Physical sciences" has the largest proportion, but the lowest increase, while the opposite is true for "Social Sciences".

2.3 BRICS Countries in bibliometric studies

The most relevant literature topic in the present context is the analysis of BRIC(S) scientific production. Some recent works tackled the topic; nevertheless no analysis of scientific collaboration between the five Countries has been performed to my knowledge.

Kumar & Asheulova (2011) *compare* scientific output of the four BRIC up to 2009. Main findings are the dramatic increase of Chinese and Indian production and the lagging behind of Russia. A rather interesting perspective is instead that proposed by Wagner & Wong (2012). Authors perform in fact a study of the global BRIC National scientific publications. Their aim is to understand whether such Countries are or not underrepresented in the Science Citation Index Expanded (SCIE). Their findings show that, unexpectedly, the level of representation of the BRIC National production is of the same magnitude of Countries as North America and Europe. Nevertheless, as authors state, visibility of national publications is much lower. Authors perform a thorough discussion on the topic of visibility on the basis of research results. They discuss the access of developing Countries to the research arena and to the “Invisible college” of science is made.

Finally, two interesting comparisons are performed respectively by Yang *et al.* (2012) and by Yi *et al.* (2013). Yang *et al.* (2012) compare BRIC Countries with G7 Countries in terms of heterogeneity of the disciplinary structure of scientific production. G7 Countries are considered as representing a high level of Science and Technology, whereas BRIC Countries are fast-breaking ones. The results of their vast analysis show “that there exists some certain relationship between the national disciplinary structure and the S&T level” (p. 507). The structure of the G7 is similar, while those of BRIC are more individually pronounced. G7 focus more than BRIC on life sciences, with the exception of Brazil. Finally, BRICs evolved towards a more balanced disciplinary structure. Yi *et al.* (2013), instead, compare the four BRIC Countries with CIVETS (Colombia, Indonesia, Vietnam, Egypt, Turkey and South Africa). The scientific production of the two groups presents several similarities, but for the fact that BRIC have had a much higher production.

This literature overview shows – through some relevant contribution – how the topic of scientific collaboration has been treated by previous authors, as well as what has been explored until now about BRICS Countries. The present work aims at contributing to these research stream with the aid of the experimental part contained in the following of the article.

3. Data mining strategy

The database exploited in the present analysis has been prepared in October – November 2013 retrieving data on the Elsevier® Scopus® web-based database[3]. Scopus has been preferred to other

[3] http://www.scopus.com/

analogous databases first of all because of its wide coverage. In fact it encompasses more than 21,000 titles, and 5,5 Millions conference papers. Scopus covers titles from all geographical regions, including non-English titles as long as English abstracts can be provided. Approximately 21% of titles are published in languages other than English or published in both English and another language; more than half of content originates from outside North America; more than 1500 journals originate in the Asian pacific region[4]. These features are particularly relevant for a work – like the present one – studying developing Countries. Moreover the structure of its website helps perform easily extensive data mining activities.

In order to perform this analysis, data on publications from 1980 to 2012 have been retrieved. Though data mining has been performed at the end of 2013, 2012 data should be considered with caution, as it they could still be partly incomplete. Nevertheless 2012 has been included for sake of greater completeness. Also, coverage of years prior to 1996 could be incomplete, as Scopus only included the archives of several major publishers. Nevertheless, with the aim of offering a better picture of the studied topics, also such data have been included in part of the present analysis.

Data mining procedure retrieved several groups of data on the number of scientific products and their Subject areas. First of all the number of scientific products for each of the five Countries. Then the number of scientific products written in collaborations between scientists of two BRICS Countries, and between the five BRICS and Germany and the USA. These data have been obtained operating on the “Advanced search” tab of the Scopus page “Search” and exploiting combinations of “AFFILCOUNTRY” (“Affiliation Country”) Scopus Code. Several trial-and-error queries have been performed – prior of downloading exploited data – in order to obtain a reliable dataset. For instance it was controlled for different denominations of Russia (“Russian Federation”), or scientific products prior to 1990 for Democratic Republic of Germany were included.

In order to calculate the total number of scientific products written in collaboration with other Countries the following procedure has been followed. First of all the number of scientific products with *only domestic affiliations* has been obtained for each of the five Countries. This has been done excluding all the other Countries in the Scopus search window. Then this number has been subtracted from the total number of scientific products from the Country in object. The result obviously renders the number of scientific products written in collaboration with any other Country.

4. Data analysis and results

[4] Data for this introduction have been retrieved via the webpage http://www.elsevier.com/online-tools/scopus/content-overview and subpages and documents therein (Accessed November 2013)

Figure 1 and Table 1 present the evolution of the number of scientific products of the five BRICS. This is the most basic indicator to start with. Figure 2 (absolute values) and Table 2 (fraction of the total production) present instead the evolution of the scientific products realized in collaboration any other Country. The dramatic growth of Chinese production after 2002 is easily seen. The other four Countries grow more slowly. Russian collaborations with foreign Countries instead decreases after 2005.

Data on intra-BRICS collaborations are shown in Table 3 and Figure 3, presenting the number of scientific products written in collaboration per year. All the trends are in growth, though strong differences are present. Finally, Table 4 and Figure 4 shows the evolution of the percentage of scientific products from each BRICS Country produced in collaboration with other BRICS Countries over the total number of collaborations. Analytically the percentage %_BRICS is defined as

$$\%_{BRICS} = \frac{\sum_i BRICS_i}{TOT_{COLLAB}} x\mathbf{100}$$

where $BRICS_i$ is the number of scientific products written in collaboration with the i^{th} BRICS Country, and TOT_{COLLAB} is the total number of scientific products written in collaboration with any other Country.

-------- INSERT TABLES 1, 2, 3, 4 AND FIGURES 1, 2, 3, 4 ABOUT HERE ---------

Inter-BRICS collaborations in general grow in absolute value; this is rather obvious given the fact that also general production grows. Fractions (Figure 4) present instead a growth for four of the Countries, and a slight decrease for China up to 2009. In this year values start growing. Interestingly most curves change angular coefficient in 2009, when the first meeting of BRIC Countries (as South Africa was not admitted yet) took place.

In order to better assess collaborations, two widely diffused normalized measures of co-occurrence/cooperation are exploited in the present context: Salton’s index (Salton & Bergkmark, 1979) and Jaccard similarity coefficient (originally coined “coefficient de communauté” by the same Jaccard) (Jaccard, 1912). Both indexes have been used by other authors in the past to study cooperation or co-occurrences. For instance Glänzel *et al.* (1999) exploit Salton’s index (as described also in Section 2). Jaccard coefficient has been exploited by Peters & van Raan (1993) in their co-word analysis of chemical engineering literature. Luukkonen *et al.* (1993) did exploit both the indicators in their analysis.

Salton's index is defined (see for instance Luukkonen *et al.*, 1993) as

$$S_{xy} = \frac{C_{xy}}{\sqrt{C_x \times C_y}}$$

while Jaccard coefficient as

$$J_{xy} = \frac{C_{xy}}{C_x + C_y - C_{xy}}$$

C_{xy} is the number of scientific products in collaboration between Countries x and y, and C_x and C_y are the total number of scientific products written in international collaboration. Both measures vary between 0 and 1.

In order to describe the strength of the collaborations between the five BRICS Countries, 2 different sets of coefficients have been calculated. In the first one, values of C_x and C_y are those of the sum of scientific products written in collaboration *with other BRICS Countries*. In the second set, instead, the values are those of *the total number of scientific products written in collaboration for each Country*. That is, it takes in account the whole strength of collaboration of each of the five BRICS with any other Country. Table 5 reports the data for the above described coefficients.

The two indexes have been used also to describe with more precision the evolution of the inter-BRICS collaborations. Figures 5 and 6 present the evolution of – respectively – Salton's and Jaccard indexes from 1996 to 2012 for all the collaborations.

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1980-2012 indexes show slightly different results according to the index and to the methodology. Considering only inter-BRICS collaborations, highest Salton's index is that of Russia-China collaborations, followed by India-China and Russia-India. Jaccard index confirms the strength of Russia-China collaboration, as well as India-China, followed by Brazil-Russia. The picture changes slightly if we consider the total size of international collaborations of the five Countries. Salton's index is the highest for Brazil-Russia, followed by Russia-China, and Brazil-India/Russia-India. Brazil-Russia Jaccard index is again the highest, followed by Brazil-India and Russia-China.

Evolution of the two indexes show that differences – though not dramatic – exist between the different collaborations, while the trends of both indexes are similar. Most trends show a change of pace around 2007-2009. Before this moment they either decrease (Brazil-Russia and Brazil-China), are stable (Russia-South Africa) or grow slowly (Brazil-India, Brazil-South Africa, Russia-China, India-South Africa). The other trends are either stable or steadily growing all along the 1996-2012 period.

The magnitude of overall (1980-2012) collaborations have also been compared with the two strongest extra-BRICS collaborations. This has been done in order to offer a more objective measure of the strength of inter-BRICS collaborations. Thus Salton's and Jaccard indexes have been calculated also for the 5 collaborations with the United States of America (which is the Country presenting the highest number of scientific products in common with the five BRICS) and Germany[5], which is also among the strongest collaborating Countries. Results are shown in Table 6.

-------- INSERT TABLE 6 ABOUT HERE ---------

These indexes should be compared with those in Table 5b, obtained with the same procedure. It is easily seen that, in almost all cases, both indexes are much stronger for the collaboration with the two extra-BRICS actors (which are nevertheless among the most important actors in World scientific production) than for those in the group. This fact shows that intra-BRICS collaborations are not among the most important scientific collaborations for the five Countries.

The role of spatial location and distance should be considered relevant in the assessment of collaborations. The five BRICS Countries are in fact located into four different continents, and this might have effect on the intensity of collaboration. This issue has been explored with a simple exercise. The number of scientific products in collaboration between BRICS and the bird's flight geographical distance in Km between the respective Capital towns are reported in Table 7 and Figure 7. A linear best-fit of the points has equation $y = -1.0064x + 12744$ and $R^2 = 0.1632$. The calculated Pearson's correlation coefficient is -0.4040. Data thus show a negative correlation between the geographical distance and the rate of collaboration. Nevertheless the points are few and the explicative power of the linear best-fit is not extremely high. Thus such data should be taken cautiously and not considered as conclusive. It must be noted that the same operation has been performed also using above calculated Salton's and Jaccard indexes. R^2 of the trend line and Pearson's correlation coefficient do not differ dramatically by those presented above, and correlation is negative in all cases; data and graphs are not reported for sake of concision.

-------- INSERT TABLE 7 AND FIGURE 7 ABOUT HERE ---------

One of the research questions asks whether the collaboration is different across different scientific areas of not. To answer this question, 26 out of the 27 Scopus subject areas have been grouped into four main areas, as shown in table 8: "Hard Sciences", "Medical Sciences",

[5] For the years prior to 1990 also the production of DDR, Democratic Republic of Germany, is considered.

“Engineering”, “Social Sciences and Humanities”. The 27th – Multidisciplinary – has not been taken in account due to its heterogeneous character. This classification, reported in Table 8, is slightly different from the Scopus classification, which consists of four Areas: “Life Sciences”, “Physical Sciences”, “Health Sciences” and “Social Sciences & Humanities”. The changes have been performed in order to better highlight the role of Engineering, due to its importance for technological Innovation. Thus the three subject categories presented in “Engineering” have been extrapolated from Scopus “Physical Sciences” Area. In the meanwhile, the four categories in “Life sciences” have been reassigned to “Hard sciences” (Agricultural and Biological Sciences) and “Medical sciences” (Neuroscience; Pharmacology, Toxicology and Pharmaceutics; Immunology and Microbiology).

-------- INSERT TABLE 8 ABOUT HERE ---------

Table 9 and Figure 8 (in four radar charts, one for each Class) report the absolute values of the scientific products written in collaboration. Figure 9 instead presents the values of Salton’s and Jaccard indexes. Finally, Figures 10 and 11 present the radar charts of the two indexes of the four Classes (respectively Salton’s and Jaccard), superimposed for sake of easier comparison. Salton’s and Jaccard indexes have been calculated using the values of coautorships *for the sole scientific areas*. It must be noted that a single journal might be in principle assigned to more than one subject category, and thus the sum of articles in scientific areas is higher than the total production of the five Countries.

-------- INSERT TABLE 9 AND FIGURES 8, 9, 10 AND 11 ABOUT HERE ---------

Results are rather mixed, and show in general the presence of an uneven pattern of collaboration across disciplines. In terms of absolute values, in “Hard sciences” the strongest collaboration links are those between Russia and China, followed by China-India and Brazil-Russia. A similar pattern is followed by collaborations in “Engineering” (though here Brazil-Russia collaborations have the same strength of India-South Africa and Brazil-China). India and China present instead the strongest ties both in “Medical sciences” and in “Social Sciences and Humanities”.

Prior to the analysis of the two indexes it must be noted that both Salton and Jaccard indexes follow a similar path in the charts, while heterogeneity between disciplines is still relevant. In “Hard sciences” the strongest ties are between Brazil and Russia, followed by Russia-China and, then, the collaborations of India with the other four Countries. In “Engineering”, instead, the strongest coefficients are those relative to the collaborations between India and South Africa, followed at distance by the collaborations of Russia with China and Brazil. The patterns of collaboration in “Medical sciences” and in “Social Sciences and Humanities” are, instead, totally different from the two above described, and present some resemblance. In both cases the stronger ties are those between India and South Africa – like in “Engineering” – but are strictly followed by India-China and (in Medicine) Brazil-South Africa.

5. Discussion and conclusions

Aim of the present work is to measure the magnitude, evolution and some features of scientific collaborations between BRICS Countries. Magnitude and evolution have been measured starting from numbers of coauthored scientific products and using specific indexes (Salton’s and Jaccard). Results on the magnitude of the coefficients show that collaborations are rather uneven in the group. Moreover they are anyway weaker than the most important collaborations with other scientific actors (U.S.A. and Germany). The evolution of the measured coefficients shows some relevant facts. The indexes for several collaborations grow faster (or even start growing after a period of decrease, as for Brazil-Russia and Brazil-China) in years 2007-2009, that is, just before the first BRICS meeting (June 16th, 2009) was going to be held in Russia. This might indicate that some sort of correlation exists between the two facts.

BRICS policies aim at fostering scientific collaboration. For instance, Sanya Declaration (Sanya Declaration, 2011), issued after the 2011 BRICS meeting held in Sanya, China, states that “We intend to explore cooperation in the sphere of science, technology and innovation” (point 28). Moreover, in the action plan, among the “New proposals to explore” it says “Hold a meeting of Senior Officials for discussing ways of promoting scientific, technological and innovation cooperation in BRICS” and “consider establishing a network of research centres of all BRICS countries” (points III.4 and I.9). Also “The BRICS Report” (BRICS 2012), issued in occasion of 2012 BRICS meeting in New Delhi, states that “Sharing technology, expertise, and research in the industrial sector is another key area of cooperation among the BRICS” (p. 173) and dedicates a section to “Cooperation in Research and Development” (p. 177). Thus, under this point of view, though no precise answer can be given to the research questions on the relations between growth in scientific collaboration and creation of BRICS, results (in particular the evolution of Salton’s and Jaccard indexes) go in the direction of assessing some kind of relation between the two. Nevertheless collaborations are still rather weak if compared with the most important extra-BRICS ones; moreover policy effect might be mitigated by trivial causes such as geographic distance between BRICS Countries. These facts might suggest that, though policies for science are going in the right direction, a further effort might be needed.

For what about the results on the different research areas, they show heterogeneity among the different scientific sectors, as well as – again – among the various bilateral collaborations. Under a general point of view the strongest area of collaboration is that of “Hard sciences”. Nevertheless research in “Medical sciences” is stronger in one case (Brazil-South Africa). Thus there is unevenness not only among the strength of collaboration between the pairs of Countries, but also about the scientific areas they collaborate on.

In conclusion, some suggestions for future research efforts on the topic, which might for instance explore the role of external Countries in intra-BRICS collaborations, as well as tackle more in detail some of the bilateral collaborations here described.

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TABLES AND FIGURES

Table 1 – Number of Scientific Products per Country, 1996 - 2012

Year	BRAZIL	RUSSIA	INDIA	CHINA	S. AFRICA
1996	8,704	31,508	20,608	28,579	4,257
1997	10,695	32,053	21,569	32,954	4,489
1998	11,679	32,657	22,019	38,469	4,537
1999	12,694	31,105	23,261	39,049	4,709
2000	13,799	31,478	23,691	45,495	4,588
2001	14,519	32,321	24,695	58,910	4,617
2002	16,745	32,552	26,714	58,339	5,224
2003	18,926	33,265	31,217	71,599	5,643
2004	22,279	36,080	34,544	107,894	6,553
2005	25,265	38,141	39,534	159,288	7,250
2006	32,839	33,954	45,696	187,065	8,110
2007	35,500	34,627	50,573	212,834	8,506
2008	40,609	35,450	57,495	249,877	9,341
2009	44,771	36,935	65,095	295,270	10,658
2010	47,832	38,074	77,342	333,035	11,634
2011	52,395	41,658	93,939	385,044	13,192
2012	57,272	41,175	101,034	400,221	14,081
TOTAL	**506,480**	**796,602**	**906,883**	**2,800,875**	**161,305**

Table 2 – Fraction of Scientific Products written in collaboration with other Countries, 1996 - 2012

Year	BRAZIL	RUSSIA	INDIA	CHINA	S. AFRICA
1996	32.5	22.8	15.2	16.7	27.3
1997	30.9	24.9	14.8	18.1	28.3
1998	31.2	25.3	16.0	16.7	29.0
1999	28.8	27.0	14.8	16.6	29.1
2000	28.3	27.2	14.6	16.1	29.7
2001	23.9	23.7	12.6	11.9	26.7
2002	24.1	23.7	13.1	15.1	27.5
2003	28.5	31.1	17.7	19.7	40.2
2004	28.5	30.9	18.1	17.2	41.7
2005	28.3	31.6	18.1	14.1	41.9
2006	24.9	34.0	17.8	14.1	41.6
2007	24.7	33.3	17.6	14.1	43.5
2008	24.2	31.2	17.0	14.1	43.4
2009	23.5	30.6	17.3	14.3	44.4
2010	23.4	29.1	16.9	14.6	43.8
2011	24.1	28.2	16.0	14.5	44.6
2012	24.5	29.5	16.1	15.5	46.8
TOTAL	**24.7**	**23.4**	**14.8**	**14.7**	**33.0**

Table 3 – Number of Scientific Products written in collaboration between BRICS Countries, 1996 - 2012

Year	BRAZIL-RUSSIA	BRAZIL-INDIA	BRAZIL-CHINA	BRAZIL-S. AFRICA	RUSSIA-INDIA	RUSSIA-CHINA	RUSSIA-S. AFRICA	INDIA-CHINA	INDIA-S. AFRICA	CHINA-S. AFRICA
1996	131	44	40	11	67	87	26	80	20	15
1997	169	52	54	19	86	111	30	86	17	10
1998	180	73	64	22	91	133	32	118	27	15
1999	162	71	67	14	83	141	20	105	32	10
2000	167	61	68	22	73	154	30	91	34	25
2001	146	62	66	12	82	157	33	86	37	14
2002	135	71	68	26	98	204	28	114	24	20
2003	189	99	92	39	123	285	24	160	50	36
2004	209	107	114	45	143	350	46	211	53	63
2005	214	159	138	53	212	430	34	278	73	71
2006	202	175	156	62	200	464	49	279	82	68
2007	222	197	145	71	237	471	58	351	102	85
2008	237	199	187	94	252	509	73	407	143	133
2009	228	239	244	125	274	524	55	447	163	136
2010	278	303	324	144	337	624	93	551	227	190
2011	369	379	481	197	363	712	141	666	298	273
2012	539	435	672	313	444	987	250	820	391	373
TOTAL	**4,008**	**2,859**	**3,050**	**1,300**	**3,493**	**6,558**	**1,072**	**5,021**	**1,804**	**1,549**

Table 4 – Percent fraction of Scientific products in collaboration with all other BRICS Countries, 1996 - 2012

Year	**BRAZIL**	**RUSSIA**	**INDIA**	**CHINA**	**S. AFRICA**
1996	8.0	4.3	6.8	4.7	6.2
1997	8.9	5.0	7.5	4.4	6.0
1998	9.3	5.3	8.8	5.1	7.3
1999	8.6	4.8	8.5	5.0	5.5
2000	8.1	5.0	7.5	4.6	8.1
2001	8.2	5.5	8.6	4.6	7.8
2002	7.4	6.0	8.8	4.6	6.8
2003	7.8	6.0	7.8	4.1	6.6
2004	7.5	6.7	8.2	4.0	7.6
2005	7.9	7.4	10.1	4.1	7.6
2006	7.3	7.9	9.1	3.7	7.7
2007	7.2	8.6	10.0	3.5	8.5
2008	7.3	9.7	10.2	3.5	10.9
2009	7.9	9.6	10.0	3.2	10.1
2010	9.4	12.0	10.8	3.5	12.8
2011	11.3	13.5	11.3	3.8	15.5
2012	14.0	18.3	12.8	4.6	20.1

Table 5 – Indexes of collaboration, years 1980 – 2012: (a) Salton and Jaccard (Italics), over the sum of BRICS collaborations ; (b) Salton and Jaccard (Italics), over total world collaborations.

a	**BRAZIL**	**RUSSIA**	**INDIA**	**CHINA**	**S. AFRICA**
BRAZIL	-	***0.1794***	*0.1328*	*0.1253*	*0.0831*
RUSSIA	0.3076	-	*0.1408*	***0.2650***	*0.0542*
INDIA	0.2352	**0.2474**	-	***0.2063***	*0.1055*
CHINA	0.2264	**0.4192**	**0.3439**	-	*0.0761*
S. AFRICA	0.1622	0.1152	0.2077	0.1610	-
b	**BRAZIL**	**RUSSIA**	**INDIA**	**CHINA**	**S. AFRICA**
BRAZIL	-	***0.0130***	***0.0111***	*0.0057*	***0.0073***
RUSSIA	**0.0262**	-	*0.0110*	***0.0111***	*0.0045*
INDIA	**0.0221**	**0.0221**	-	*0.0093*	*0.0097*
CHINA	0.0134	**0.0236**	0.0213	-	*0.0033*
S. AFRICA	0.0159	0.0107	0.0213	0.0104	-

Table 6 – Salton and Jaccard indexes for the collaborations of BRICS with the USA and Germany, years 1980 – 2012

SALTON	**BRAZIL**	**RUSSIA**	**INDIA**	**CHINA**	**S. AFRICA**
USA	0.0979	0.0814	0.1000	0.1763	0.0559
GERMANY	0.0440	0.1270	0.0509	0.0549	0.0326
JACCARD	**BRAZIL**	**RUSSIA**	**INDIA**	**CHINA**	**S. AFRICA**
USA	0.0245	0.0241	0.0258	0.0732	0.0093
GERMANY	0.0156	0.0532	0.0185	0.0269	0.0081

Table 7 – Number of scientific products in cooperation vs. geographical distance

Countries	Pubblications	Capital towns	Distance in Km
BRAZIL – RUSSIA	4,008	Brasilia – Moscow	11,296
BRAZIL –INDIA	2,859	Brasilia – New Dehli	14,573
BRAZIL – CHINA	3,050	Brasilia – Beijing	16,961
BRAZIL – S. AFRICA	1,300	Brasilia – Capetown	7,340
RUSSIA – INDIA	3,493	Moscow – New Dehli	4,346
RUSSIA – CHINA	6,558	Moscow – Beijing	5,800
RUSSIA – S. AFRICA	1,072	Moscow – Capetown	10,148
INDIA – CHINA	5,021	NewDehli – Beijing	3,781
INDIA – S. AFRICA	1,804	NewDehli – Capetown	9,317
CHINA – S. AFRICA	1,549	Beijing – Capetown	12,970

Table 8 – Division of Scopus Subject Areas into four Classes

HARD SCIENCES	**MEDICAL SCIENCES**
Agricultural and Biological Sciences	Biochemistry, Genetics and Molecular Biology
Chemistry	Dentistry
Earth and Planetary Sciences	Health Professions
Energy	Immunology and Microbiology
Environmental Science	Medicine
Materials Science	Neuroscience
Mathematics	Nursing
Pharmacology, Toxicology and Pharmaceutics	Veterinary
Physics and Astronomy	
	SOCIAL SCIENCES AND HUMANITIES
ENGINEERING	Arts and Humanities
Chemical Engineering	Business, Management and Accounting
Computer Science	Decision Sciences
Engineering	Economics, Econometrics and Finance
	Psychology
	Social Sciences

Table 9 – Research Area collaborations: absolute values

DATA 1980-2012	BRAZIL-RUSSIA	BRAZIL-INDIA	BRAZIL-CHINA	BRAZIL-S. AFRICA	RUSSIA-INDIA	RUSSIA-CHINA	RUSSIA-S. AFRICA	INDIA-CHINA	INDIA-S. AFRICA	CHINA-S. AFRICA
SCI	4389	2770	2767	952	3764	7049	1054	4783	1646	1310
MED	478	874	849	789	362	789	270	1418	696	564
ENG	403	335	465	95	305	1037	157	883	444	336
SSH	42	96	115	72	37	83	33	233	123	101

Figure 1 – Number of Scientific Products per Country, years 1996 - 2012

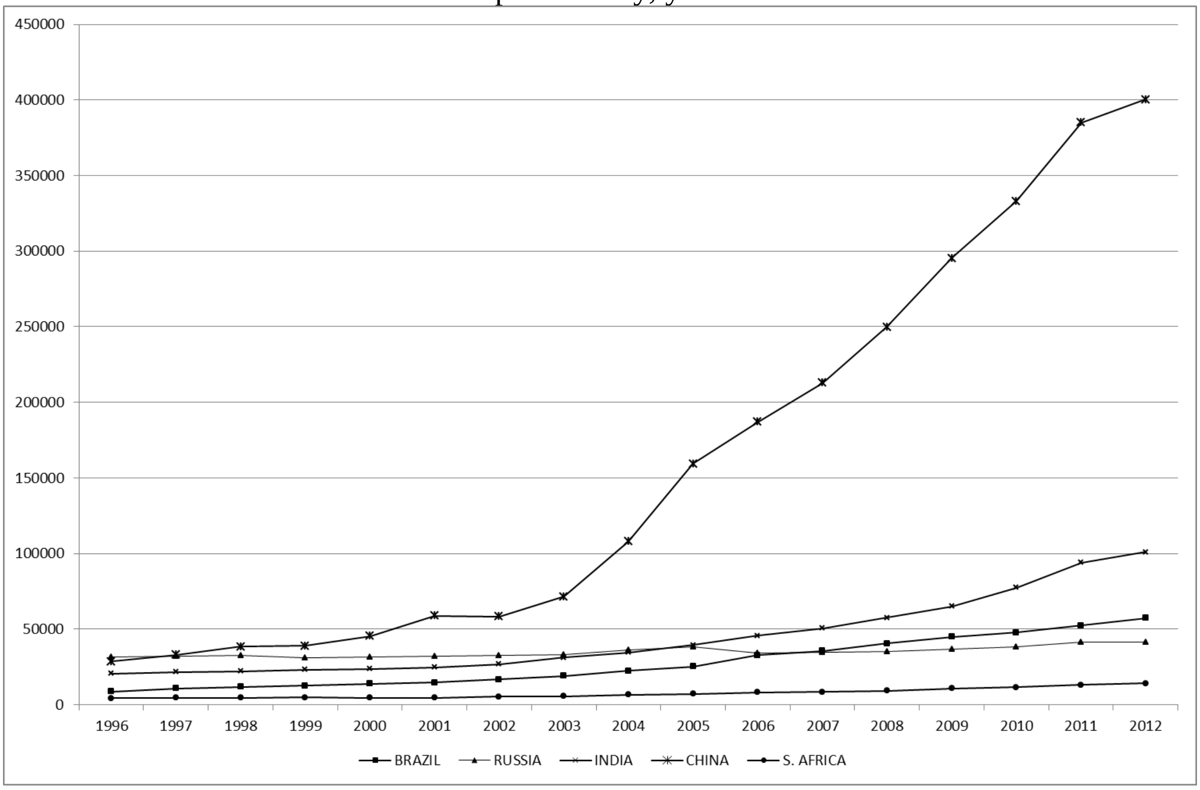

Figure 2 - Number of Scientific Products per Country written in collaboration with other Countries, years 1996 – 2012

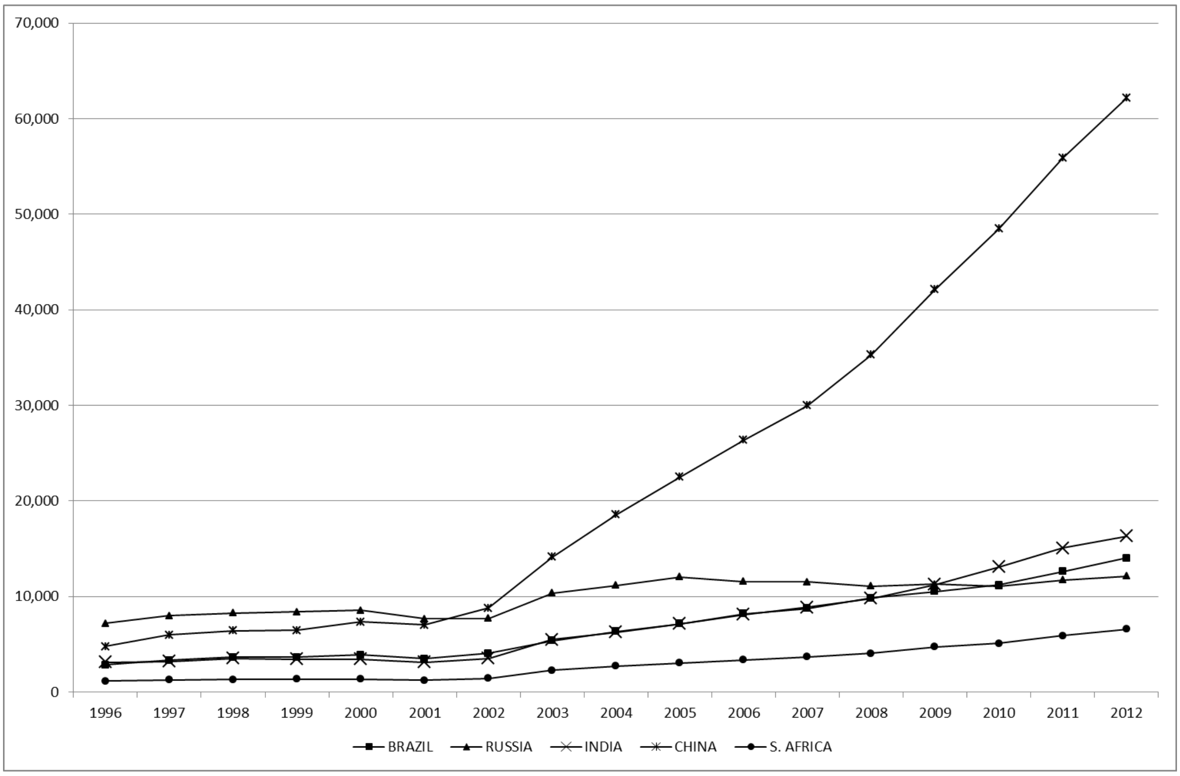

Figure 3 – Number of Scientific Products in collaboration, years 1996 - 2012

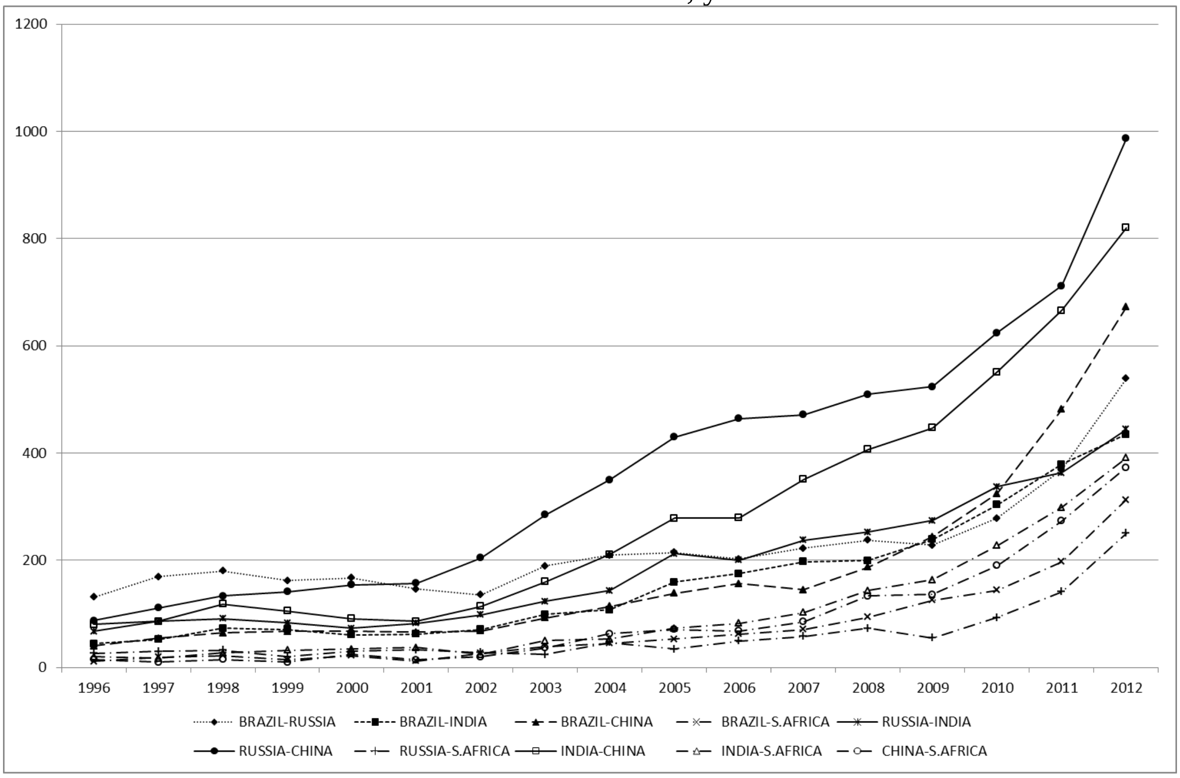

Figure 4 – Fraction of Scientific products in collaboration with BRICS Countries, years 1996 - 2012

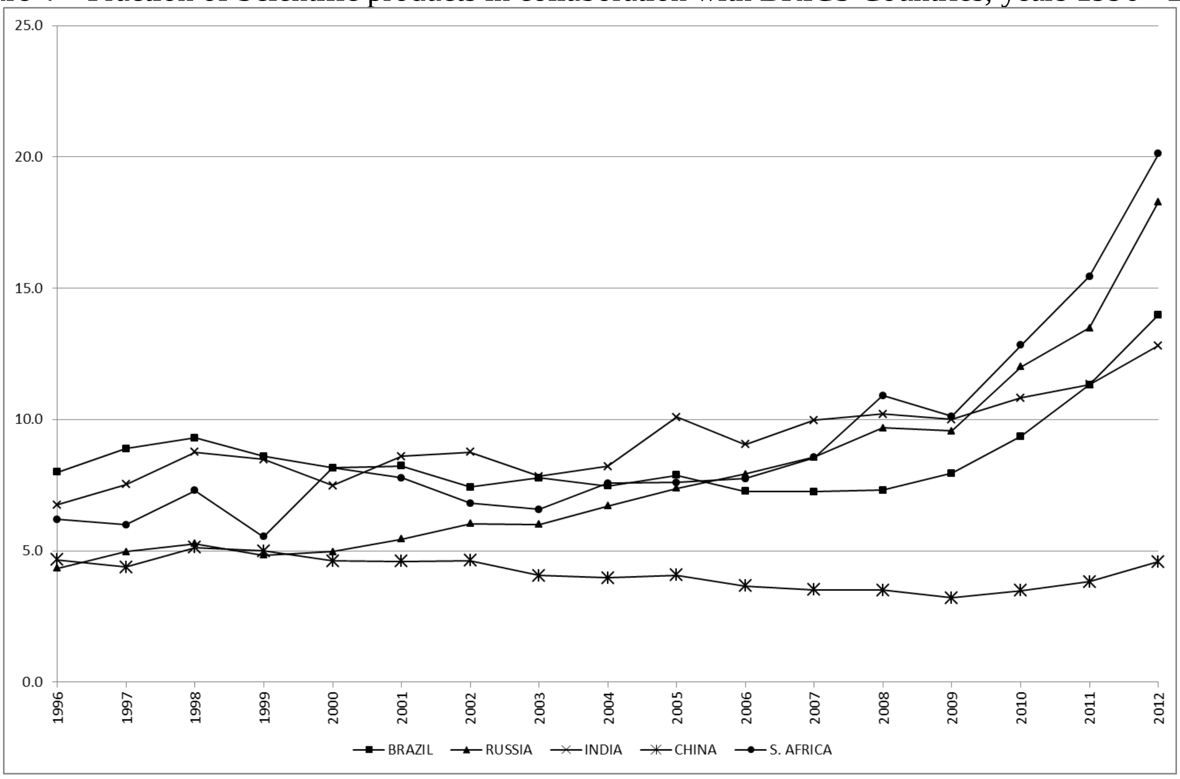

Figure 5 – Evolution of Salton's index, 1996-2012 (values are multiplied by a factor 1,000)

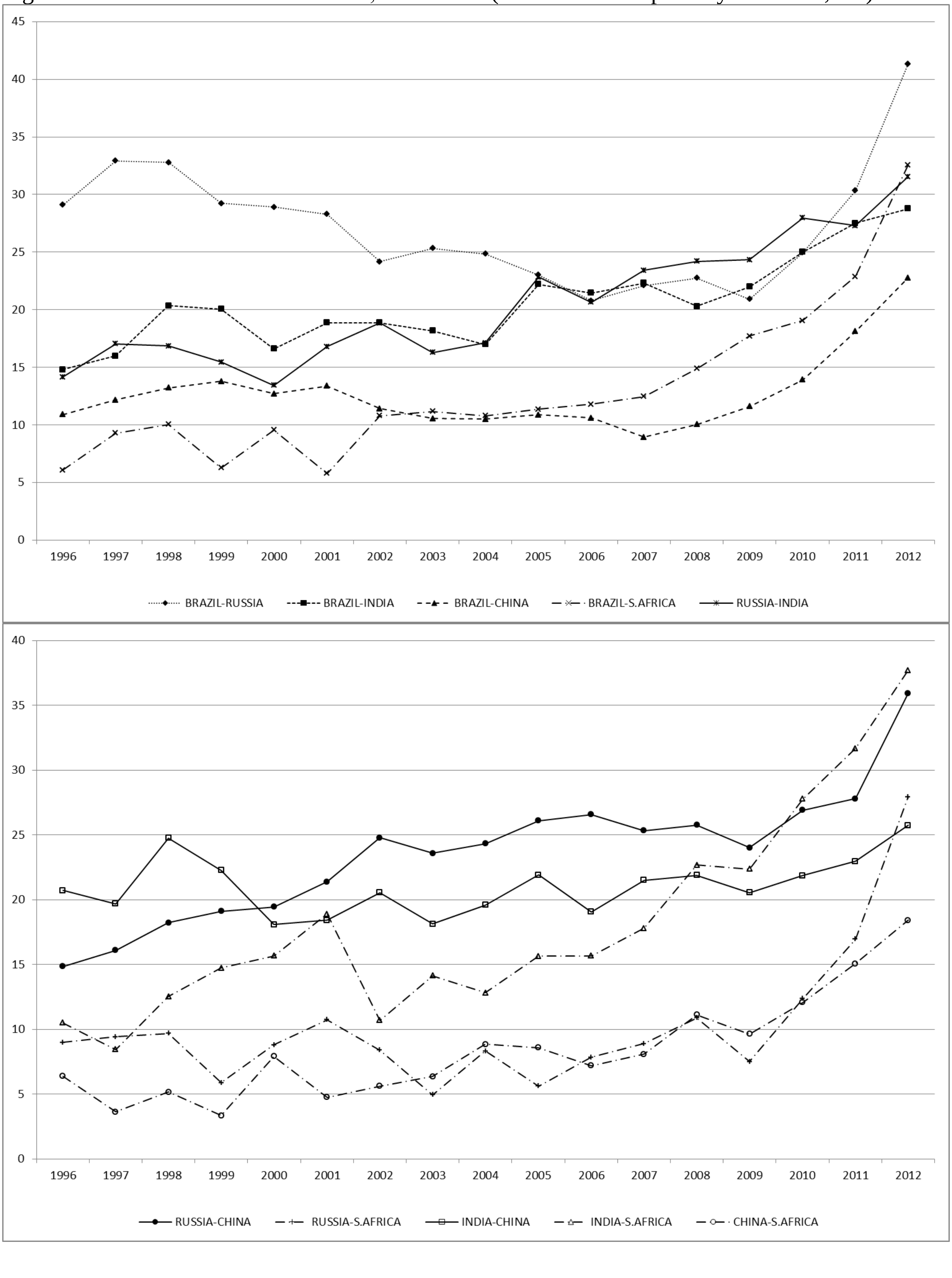

Figure 6 – Evolution of Jaccard index, 1996-2012 (values are multiplied by a factor 1,000)

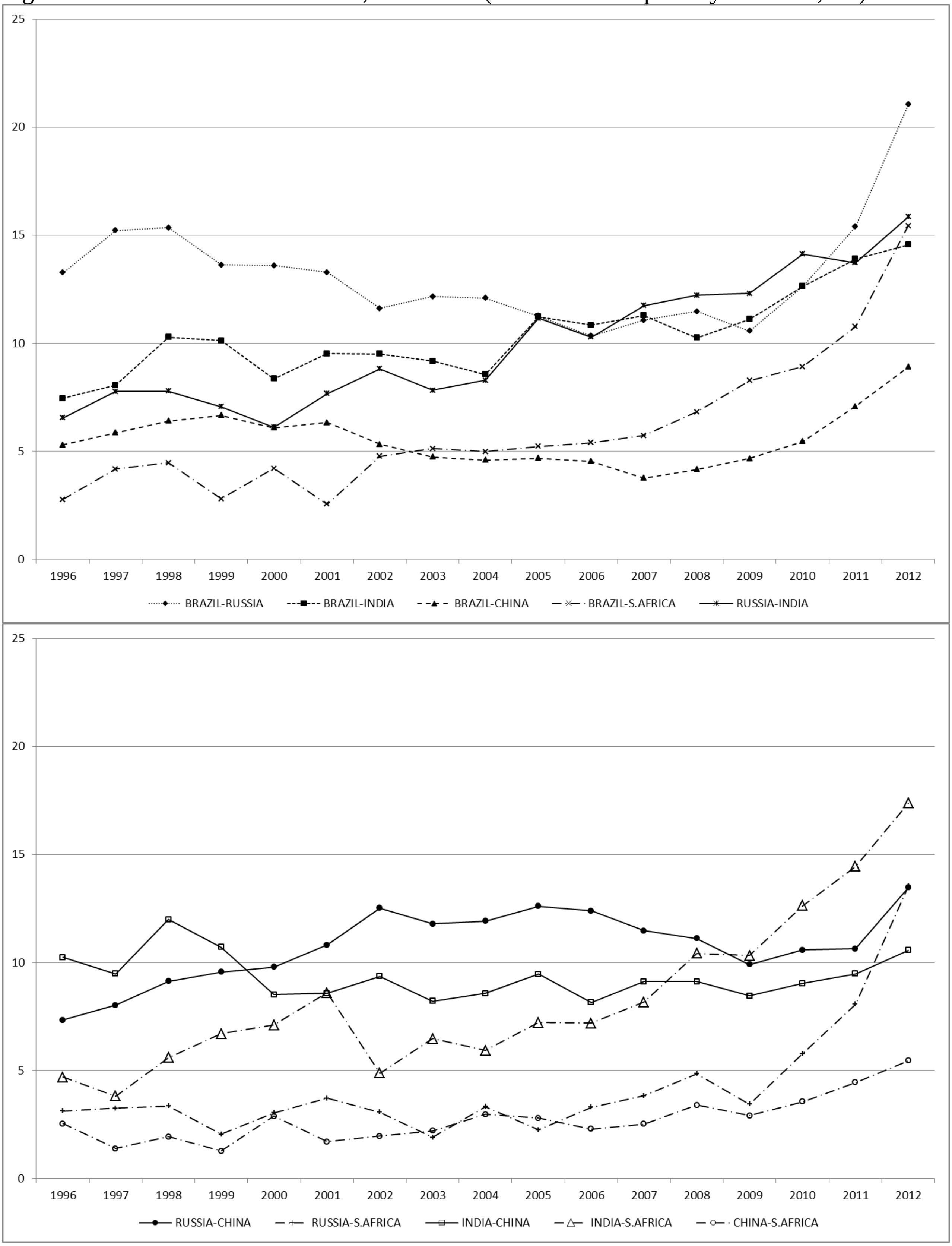

Figure 7 – Number of scientific products in cooperation vs. geographical distance

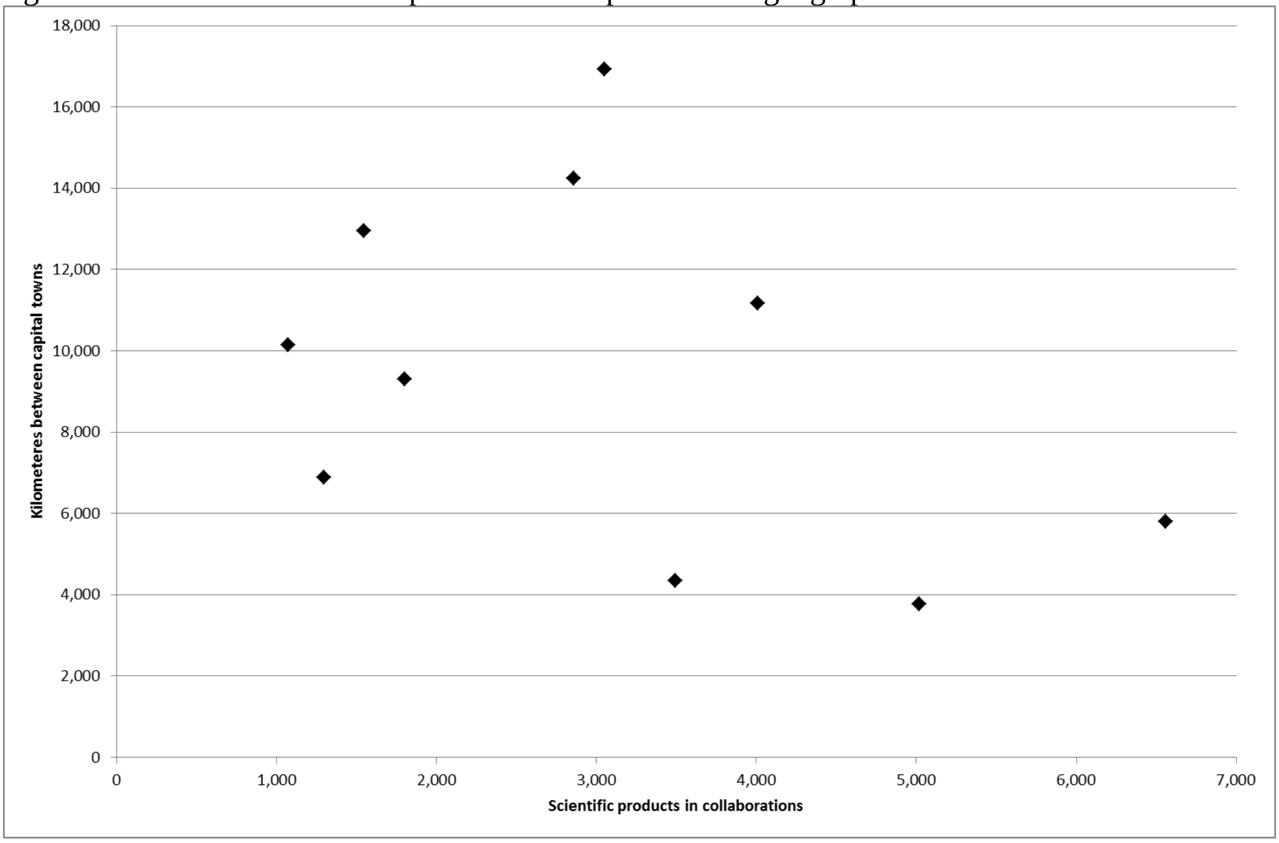

Figure 8 – Research Area collaborations: absolute values

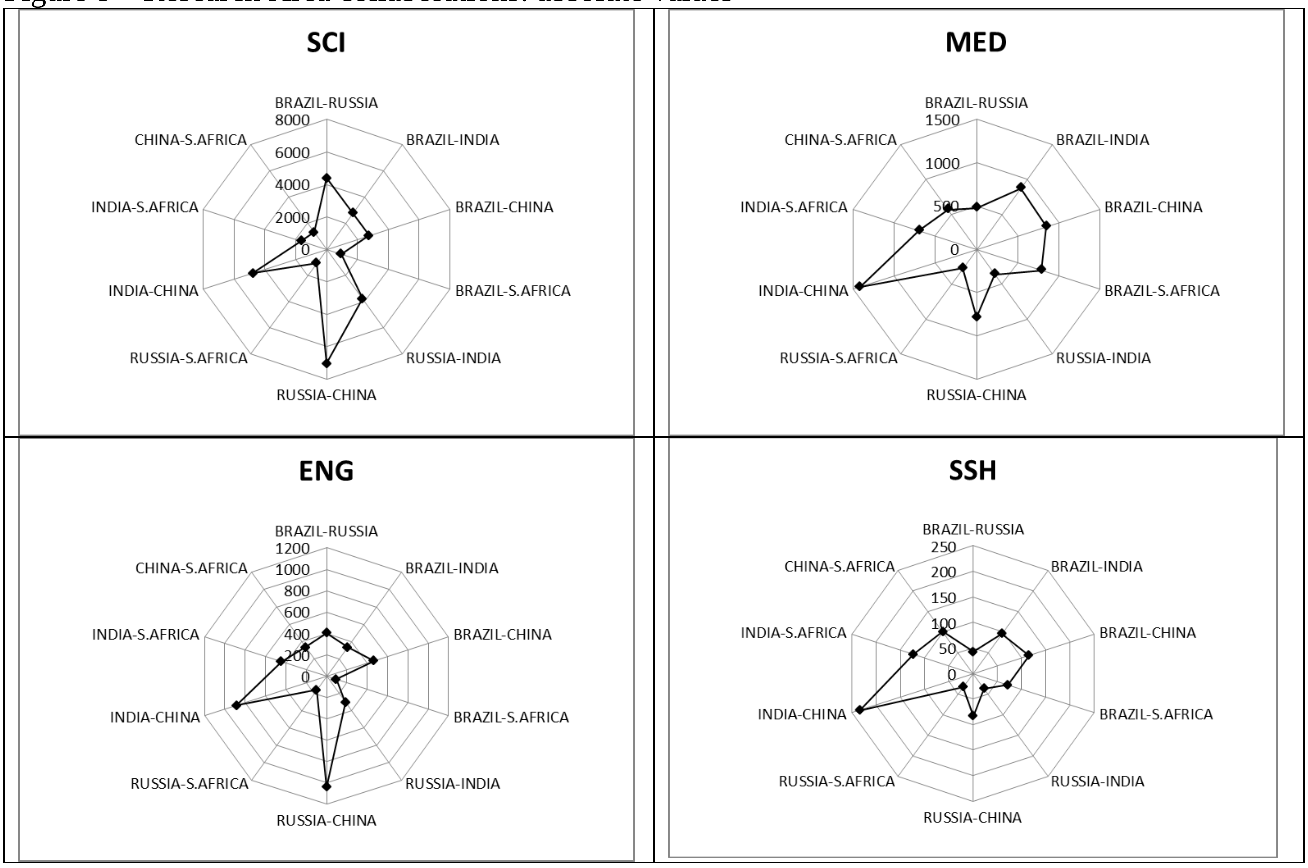

Figure 9 – Research Area collaborations: Salton (continuous line) and Jaccard (broken line) indexes

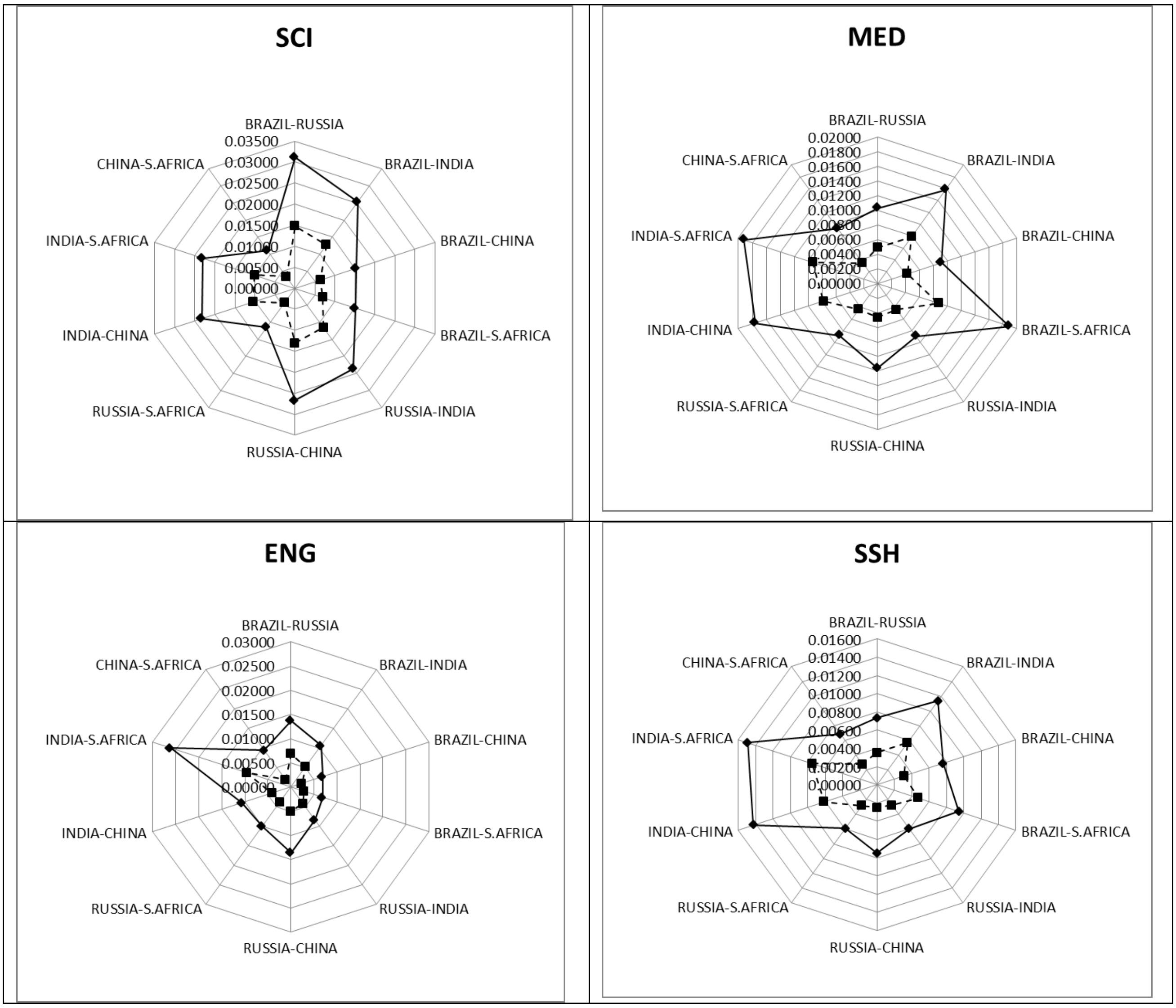

Figure 10 – Research Area collaborations: Salton indexes

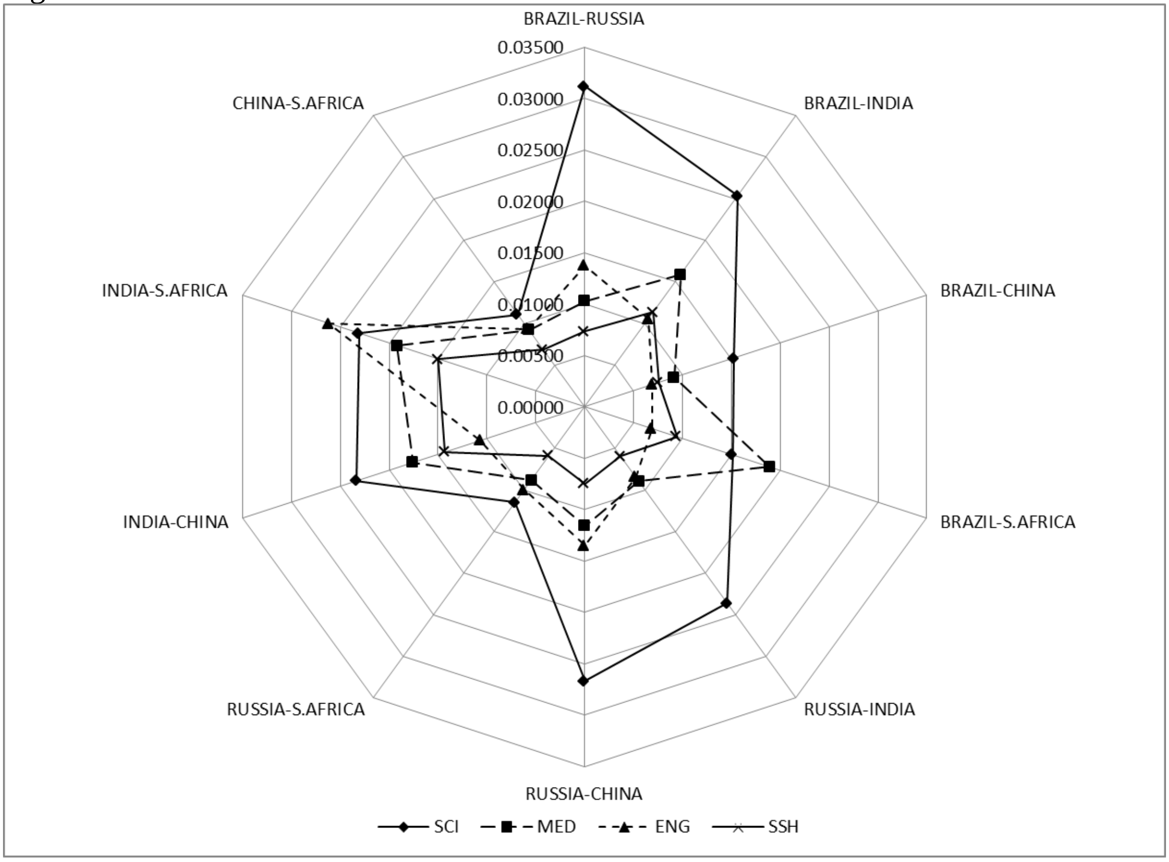

Figure 11 – Research Area collaborations: Jaccard indexes