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# Scientific collaboration framework of BRICS countries: an analysis of international coauthorship

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**Abstract** International scientific collaboration is strategic for the growth of a country, in particular for developing countries. Among these ones the five Brazil, Russia, India, China and South Africa (BRICS) have a relevant role, also because they are joined in an association to foster mutual development. The present article studies the network of international scientific collaborations existing around the five BRICS. It does so considering the number of coauthored scientific product having authorship shared between two different countries of a group of 70: the five BRICS plus 65 countries strongly collaborating with them. Absolute numbers of coauthored scientific products are arranged in a contingency table, and Probabilistic Affinity Indexes (chosen due to size independency) are then calculated. Indexes show the relative strength of inter-BRICS collaborations with respect to the network surrounding the five countries. At the end of the work obtained results are discussed and commented, and policy suggestions are offered.

**Keywords** BRICS countries · International scientific collaboration · Probabilistic affinity index · Network analysis

## Introduction

BRICS countries are a relevant group of countries among the fast growing ones, and their importance has been increasing in the last decades. These five countries—Brazil, Russia, India, China and South Africa—are joined in an association since the end of

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the 2000s. Their majors meet regularly in one of the five Capital towns, in order to study common development strategies and to sign memorandums of agreement or documents of other kind. Thus they are often considered as a group and studied as such.

In a recent article Finardi (2015) has explored the patterns of intra-BRICS Scientific collaborations. There is a twofold perspective in studying such specific topic. First of all scientific collaboration is a relevant medium of interaction between countries. Thus deepening their nature can show relevant characters of the existing inter-country relations. Second, in the recent past the ministers of BRICS countries have signed documents stating the relevance of scientific collaboration for the common development strategy. The most relevant of such documents is probably the "Cape Town Declaration" (BRICS 2014).[1] Thus deepening existing scientific collaborations among the five countries can shed light on the basis on which such collaborations are intended to be built in the next future.

The present work goes one step beyond the above cited work of Finardi (2015). It aims in fact at contextualizing inter-BRICS scientific collaborations, framing them into a worldwide network of inter-country bilateral collaborations. To this aim the present work (as done in the former) relies on an index—the Probabilistic Affinity Index, which will be exhaustively described in the following of the article—calculated starting from a contingency matrix of values. This index has the advantage of being uninfluenced by the magnitude of internal scientific production of the considered countries. In this way it is able to measure the real strength of collaborations. Considering a wider number of countries in the matrix (70 in the present work, for a total number of 4900 collaborations) allows us to calculate coefficients that are built on the whole set of international collaborations (measured with coauthorship). This in turn allows us to measure the relative strength of inter-BRICS research collaboration *in the global context* of their international scientific collaborations.

Thus the present article is driven by the following research questions: How is the pattern of international scientific collaboration of BRICS countries designed? Are inter-BRICS scientific collaborations relevant—on a quantitative basis—with respect to the other bilateral collaborations? Or, on the contrary, are such collaborations weak, thus justifying the present effort of BRICS majors, and possibly even a more intensive one, to foster scientific collaboration between the five countries? In order to respond to these questions, this work performs an analysis extended to the total collaboration pattern of 70 countries. These ones are the 5 BRICS plus 65 other countries, chosen among those having the highest values of scientific products realized in collaboration with the BRICS.

The remainder of this work is organized as follows. Second section presents a literature overview and theoretical framework, discussing the features of BRICS and the metrics used in this work, as well as the nature of scientific collaboration. Third section presents instead the methodology and fourth section the obtained results. Finally, fifth

[1] This document has been signed in Cape Town, South Africa, at the Science, Technology and Innovation Ministerial Meeting held in that town on February 10th, 2014. In this Declaration Ministers make relevant affirmations on the topic of scientific collaboration. They in fact "reaffirm the vision to strengthen the BRICS partnership for common development and advance collaboration […] stress the paramount importance of science, technology and innovation" (p. 1, passim). Besides this statement they also "agree to enter into a BRICS Memorandum of Understanding on Cooperation in Science, Technology and Innovation" (p. 2).

section draws the conclusions from the analysis of results and sketches policy suggestions.

## Literature overview and theoretical framework

The present section discusses several topics that are relevant in the context of the present work. First of all it reviews some recent work discussing the features and policies of BRICS, thus updating the literature overview of Finardi (2015). Reference will also be made to the comprehensive literature overview and theoretical framework of that work; also, for sake of brevity, some of the references presented therein will be omitted in the present work. Then the theoretical framework will discuss shortly past contributions presenting the study of inter-country scientific collaborations. This in turn will introduce the topic of the metric exploited in the present study. Surreptitiously also the role of coautorship in the measure of inter-country collaborations will be introduced.

### Some relevant recent studies on BRICS countries

The historical path of BRICS countries starts at the beginning of the 2000s, when the acronym Brazil, Russia, India, China (BRIC) was coined. Subsequently the four countries did create an association. Their leaders started meeting regularly in formal summits in 2009. Subsequently South Africa joined the Association to form BRICS, with the aim of mutual collaboration to improve the economies of the five countries. As discussed in the introduction scientific research and cooperation is a relevant topic in the pot of BRICS meetings. Hence the importance of the present study.

Radulescu et al. (2014) assess the role of BRICS countries in the international context. According to their results the expansion of BRICS is due to a sum of factors, heterogeneous among countries: natural resources, low labour costs, high rates of investment. The study does not neglect weaknesses such as the high level of corruption or the different political ideologies, while tries to perform a forecast of possible scenarios.

The important economic and social role of natural resources in BRICS is instead discussed more specifically by Wilson (2015). The article "explores the BRICS' emerging status as 'resource powers'" (p. 223) given the fact that all the five countries are rich of natural resources. The underlying hypothesis is obviously the idea that the rise of BRICS is connected with this status. According to the analysis "It is through the mechanism of resource nationalist policies that the BRICS governments have leveraged this wealth" (p. 235).

Sustainable development of BRICS is the core topic of the work of Santana et al. (2014). Aim of the authors is to "discuss the performance of the countries in the BRICS group with regards to sustainable development" (p. 259) and "to compare the efficiency of the BRICS countries in transforming productive resources and technological innovation into sustainable development" (p. 263). Results show that the most efficient in the group under this point of view is Brazil. China, conversely, though presenting the highest GDP of BRICS, is third in this ranking. This suggests China should improve its efficiency to reach a long term growth.

Finally, Robinson (2015) clarifies the challenge of BRICS to global capitalism. In specific the article examines empirical data to argue that "the concept of the transnational state provides a more satisfying explanatory framework for understanding the BRICS phenomenon than the variety of realist approaches".

Some recent works tackle instead scientometric and bibliometric topics. It is the case for instance of Wang and Li-Ying (2014) who study USPTO patents of the four BRIC countries in order to devise their contribution to the global innovation system, their level of internationalization and their rate of convergence. Results show an increasing contribution of the four countries to the global innovation system, notwithstanding the still relatively low absolute significance.

An interesting perspective is that of Wong and Wang (2015) who devise from the analysis of publications and patents the global scientific and technological trajectory of the five countries. While indexes for scientific production show an emerging role of China within the group, technological activity shows a convergence according to the exploited indicators. This, according to the authors' opinion, "coincides with the existing development context of BRICS" (p. 97).

On the more specific topic of scientific collaborations of BRICS countries a descriptive effort to highlight is that of Singh and Hasan (2015) who present figures on the scientific production (number of scientific products) of the five countries, and on their international collaboration, both mutual and with other countries.

Another effort in this sense is that of Rensburg et al. (2015). They affirm that "The analysis of research collaboration has indicated that BRICS nations have not established good research partnerships. Similarly […] students from BRICS do not consider other BRICS nations as attractive destinations for study abroad. All this leads to the conclusion that BRICS has to enhance mutual research collaboration" (p. 817).

Finally, the relevance of BRICS scientific production in terms of received citations is studied by Bornmann et al. (2015) on a sample of highly cited papers. Results show that BRICS cooperate with countries leaders in terms of scientific production.

## Inter-country scientific collaborations: use of coauthorship and exploited metrics

Several past works study inter-country scientific collaborations. A seminal work is that of Narin et al. (1991) who study scientific cooperation in Europe, showing (among other findings) that "the coauthorship patterns in the Community have strong linguistic and historical components" (p. 320). The paper uses coauthorship as an instrument to measure cooperation. This finding has to be taken in account in the context of the present work. Luukkonen et al. (1992) perform instead a study on a wider sample of countries. Their analysis of the collaboration network of countries exploits a measure of the family of the "probabilistic indexes". This citation is not accidental: the present work in fact favours a measure of this family, the Probabilistic Affinity Index, with respect to other metrics such as Salton's and Jaccard's indexes. The reasons for this choice will be discussed in the next section. These last two indexes are instead used by Luukkonen et al. (1993) who, closer to our effort, create (seminal) network maps of international cooperation. It is also relevant to cite the works of Okubo et al. (1992) and of Miquel and Okubo (1994). In the former of the two, authors use Correspondence Factorial Analysis and Minimum Spanning Tree to measure collaborations via coauthorship of scientific articles. As in the present work multinational cooperation is not accounted for, and full count method (that is, each scientific product is fully credited to each country) is exploited. In the latter article authors extend to practical applications the same methodology. More in specific authors study the profile in terms of importance of research areas in the scientific production of each country.

When studying research collaborations a relevant topic to discuss is that of counting methods. In fact scientific products written in collaboration can be fully credited to each partner, or instead fractionally credited to contributors according to specific rules. A comprehensive analysis of the various methods, and of the possible biases they introduce, is performed by Gauffriau et al. (2007). Nevertheless, as the present work deals with bilateral scientific collaborations, it was preferred, like in Finardi (2015), to use a "full count" method to distribute scientific products among partners.

Finally, besides the above discussed topics, it is also relevant to discuss the meaning of the nature of research collaboration. As described above, the present work exploits coauthorship, and thus the number of scientific products coauthored between authors of different countries, as a metric to measure international collaboration. Katz and Martin (1997) did answer to the question on "what is a collaboration?". Besides defining different types of collaborators to a research, their main result under this point of view is the statement affirming the "fuzziness" or "ill-defined border" of a research collaboration: "Perception regarding the precise location of the 'boundary' of the collaboration may vary considerably across institutions, fields, sectors and countries as well as over time" (p. 8). Besides this idea, it must nevertheless be noted that coauthorship of scientific works is only one of the possible outcomes of any research collaboration, and thus it is only one of the forms in which collaboration can be expressed. Other forms, such as international programmes, collaboration in great infrastructures, international competitive research financing, exist. Moreover, as Melin and Persson (1996) state, "collaboration does not necessarily lead to co-authored papers" (p. 364). Nevertheless coauthorship is one of the most relevant outcomes of collaboration provided that publication of scientific results is one of the classical outcomes of research activities. It is feasibly by virtue of this fact that de Beaver and Rosen (1978, 1979a, b) studied in their seminal works ''collaborative scientific research, formally acknowledged by co-authorships of scientific papers'' (1978, p. 65).

## Methodology

Data extraction has been performed in June 2015 retrieving data on the Elsevier® Scopus® web-based database.[2] The reason for this preference is twofold. First of all Scopus website allows easier extensive data mining activities. Then it has a wider coverage, in particular of non-English and non-American-based literature, providing non-English articles as far as an English abstract is provided.[3] Thus it seemed meaningful to exploit this database, also due to the countries studied in the present work.

Data have been obtained working on the "Advanced search" window of Scopus, using the "AFFILCOUNTRY" (affiliation country) search code. In this way the numbers of scientific products authored in each country, starting from the five BRICS, has been obtained. Once obtained the (numbers of) scientific products of a specific country, also the

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

[3] The Scopus Content Coverage Guide (https://www.elsevier.com/__data/assets/pdf_file/0007/69451/sc_content-coverage-guide_july-2014.pdf, accessed January 2016) presents the following data on Scopus: it encompasses more than 22,000 active titles, and 6.4 Million conference papers; titles from all geographical regions are covered, including non-English titles: approximately 21 % of titles in Scopus are published in languages other than English (or published in both English and another language); more than half of Scopus content originates from outside North America representing various countries Europe, Latin America and the Asia Pacific region.

numbers of products written in collaboration with other countries can be retrieved in the search mask.

The database exploited in the present work contains numbers of scientific products realized in collaboration between BRICS countries and a set of other countries, as well as all the scientific products written in collaboration between all the non-BRICS countries. The total number of considered countries is 70: the 5 BRICS plus other 65 countries. These countries are those presenting the highest scientific production in collaboration with the 5 BRICS in the years 1996–2013. The names have been extracted from the list of countries collaborating with BRICS. The names of the first 25 countries having the highest number of scientific products in collaboration with each BRICS country have been combined together in a first group. Then, proceeding top-down in the lists, other countries have been added to this group, privileging those collaborating with the most number of BRICS. Once prepared this list, for each of the 65 countries data for the collaboration with the other countries in the group have been obtained. Mutual consistency has been checked. That is, once obtained data for country A, the number of scientific products in collaboration with country B has been checked for consistency retrieving country A in the list of countries obtained starting from country B. All obtained data have been arranged in a 70 × 70 contingency table.

From this dataset a probabilistic index, the Probabilistic Affinity Index (PAIs from now on) have been calculated (see for instance Zitt et al. 2000; Luukkonen et al. 1993). Other types of measures (absolute values, fractional values, Salton's indexes, Jaccard coefficients) have not been exploited in the present work (see also Finardi 2015). This because PAIs are the only indexes that are size independent from the country's total number of scientific products. Thus this indicator has been preferred as the sole able to disentangle the strength of collaborations from other factors.

According to the above cited references PAIs have been calculated with the following formula:

$$\mathrm{PAI} = \frac{C_{\mathrm{tot}} C_{xy}}{C_x C_y}$$

where $C_{\mathrm{tot}}$ is the grand total of the contingency table; $C_{xy}$ is the number of scientific products written in collaboration between the two generic $x$ and $y$ countries; $C_x$ and $C_y$ are the marginal sums for each of the two generic $x$ and $y$ countries. As above described the counting method adopted is "full count": scientific products have been fully credited to each of the two collaborating countries.

The contingency table is, in principle, incomplete. In fact diagonal elements ("self-collaborations") have to be filled. To do so two methodologies are possible. The first one is to simply insert the values of the total scientific production of the country. As Finardi (2015) shows PAIs calculated in this way are still not totally size independent. Thus in the present work an iterative reconstruction method has been preferred (see for instance de Solla Price 1981; Noma 1982; Tijseen et al. 1987; de Leeuw and van der Heijden 1988). First of all diagonal values have been all set to 0. Then the following formula has been applied:

$$D_{xy} = \frac{C_x C_y}{C_{\mathrm{tot}}}$$

where $D_{xy}$ is the calculated diagonal element (in this case $x = y$); $C_{\mathrm{tot}}$ is the grand total of the contingency table; $C_x$ and $C_y$ (equal in this case) are the marginal sums corresponding to the row and column of the considered country. Once the values of $D_{xy}$ have been obtained another calculation is made in which the new values of $D_{xy}$ are considered in the marginal sum. The process is iterated $n$ times ($n = 13$ in the present case) until the point where two following results are identical. At this point the contingency table can be used to calculate PAIs using the above described formula.

Obtained data have been synthesized in tables, presented and discussed in the next section. Besides presenting data in tables, instruments of the network analysis have been exploited. Pajek 4.04[4] has been used for the visualizations of the network. In order to improve visualization of the network, all PAIs values have been rescaled in a 1–10 scale. The Kamada and Kawai (1989) layout algorithm has been used to graphically represent the network. This algorithm produces regularly spaced results, especially for those connected networks that are not very large, that is, below five hundred vertices. Indeed, Kamada–Kawai algorithm seems in our case to produce more stable results than other layouts, such as Fruchterman–Reingold, which is instead suggested for larger networks (Leydesdorff and Rafols 2009). In the figures of the present work the thickness and grey-shade of the links are proportional to the values of the PAIs. The highest the PAIs, the thicker and darker the line between the two countries. Conversely, the more Probabilistic Affinity Indexes is low, the more the line between the two countries is thin and light. The size of the nodes is the same for all of them.

## Results

Table 1 contains the total pattern of BRICS countries' scientific collaboration expressed with PAIs. The table is an extract of the complete 70 × 70 table of obtained PAIs. In order to better highlight the relative strength of the collaborations the background of the cells is shaded: the darker the colour the higher the value of the PAI.

Tables 2, 3 and 4 have been further extracted from Table 1. Table 2 presents all the indexes above the value of 1, whereas Table 3 those above 2 and Table 4 those above 5. The meaning of shadings remains the same. It is easily seen that inter-BRICS collaborations soon disappear. Three of them (those in the Brazil–India–South Africa triangle) are present in Table 2 only; Tables 3 and 4 do not present any of the inter-BRICS collaborations.

Figures 1, 2 and 3 contain the graphs resulting from the network analysis of the calculated PAIs. Figure 1 contains the whole path of international collaboration surrounding the five BRICS countries. In this figure, the values of the PAIs have been arranged in ascending order so the darker and thicker lines have been automatically positioned in the first layer (forefront) while the lighter lines on the background.

Figures 2 and 3 present an extract of the whole network. Figure 2 considers only the links having normalized PAI higher than 9.00. Such value has been chosen in order to improve network view and focus on the strongest relationship among the countries. Figure 3 presents the network centered on the five BRICS countries, highlighting only the collaborations among them, regardless of the values of the PAIs. Again it is easily seen that the links between the five BRICS countries are rather weak if inserted into—and compared with—a large path of international collaborations.

[4] Pajek is one of the most popular software used to analyze social networks through numerical or visual representation. See http://vlado.fmf.uni-lj.si/pub/networks/pajek/ (visited January 2016).

**Table 1** Total pattern of BRICS countries' scientific collaboration—PAIs

| | BRAZIL | CHINA | INDIA | RUSSIA | S. AFRICA |
|---|---|---|---|---|---|
| Algeria | 0.32 | 0.18 | 0.58 | 0.34 | 0.86 |
| Argentina | 5.41 | 0.34 | 0.80 | 0.62 | 1.45 |
| Armenia | 1.60 | 0.57 | 1.00 | 2.77 | 2.11 |
| Australia | 0.80 | 1.75 | 1.09 | 0.45 | 1.91 |
| Austria | 0.66 | 0.41 | 0.60 | 0.94 | 0.82 |
| Belarus | 1.38 | 0.55 | 0.85 | 5.36 | 1.35 |
| Belgium | 0.82 | 0.41 | 0.56 | 0.86 | 1.11 |
| BRAZIL | 1.00 | 0.43 | 1.05 | 0.92 | 1.08 |
| Bulgaria | 0.85 | 0.37 | 1.19 | 1.98 | 0.53 |
| Canada | 1.03 | 1.25 | 0.92 | 0.58 | 0.97 |
| Chile | 3.11 | 0.30 | 0.59 | 0.69 | 1.59 |
| CHINA | 0.43 | 1.00 | 0.69 | 0.58 | 0.50 |
| Colombia | 4.21 | 0.54 | 1.26 | 0.96 | 1.24 |
| Croatia | 1.07 | 0.47 | 1.18 | 1.16 | 0.80 |
| Cuba | 6.35 | 0.40 | 0.81 | 0.54 | 1.13 |
| Czech Republic | 0.99 | 0.42 | 0.95 | 1.78 | 0.91 |
| Denmark | 0.64 | 0.53 | 0.50 | 0.71 | 1.02 |
| Egypt | 0.71 | 0.53 | 1.33 | 0.45 | 0.77 |
| Estonia | 0.84 | 0.39 | 0.92 | 1.71 | 0.43 |
| Finland | 0.62 | 0.51 | 0.66 | 1.81 | 0.63 |
| France | 1.25 | 0.55 | 0.78 | 1.24 | 0.81 |
| Georgia | 1.57 | 0.62 | 1.01 | 2.35 | 1.64 |
| Germany | 0.78 | 0.65 | 0.91 | 1.69 | 0.79 |
| Greece | 0.65 | 0.36 | 0.61 | 0.93 | 0.70 |
| Hong Kong | 0.27 | 10.87 | 0.72 | 0.20 | 0.41 |
| Hungary | 0.76 | 0.40 | 0.96 | 1.16 | 0.94 |
| INDIA | 1.05 | 0.69 | 1.00 | 0.82 | 1.70 |
| Indonesia | 0.57 | 0.60 | 1.45 | 0.18 | 0.94 |
| Iran | 0.65 | 0.52 | 1.84 | 0.62 | 1.03 |
| Ireland | 0.77 | 0.60 | 0.83 | 0.89 | 0.83 |
| Israel | 0.70 | 0.41 | 0.82 | 1.24 | 0.99 |
| Italy | 0.96 | 0.35 | 0.67 | 1.05 | 0.59 |
| Japan | 0.60 | 2.49 | 1.52 | 1.22 | 0.55 |
| Kazakhstan | 0.33 | 0.46 | 1.22 | 9.72 | 0.38 |
| Kenya | 0.73 | 0.45 | 1.28 | 0.09 | 8.32 |
| Latvia | 0.50 | 0.14 | 0.34 | 3.21 | 0.62 |
| Lithuania | 0.94 | 0.43 | 0.90 | 1.65 | 0.35 |
| Malaysia | 0.64 | 1.14 | 5.55 | 0.25 | 0.87 |
| Mexico | 2.27 | 0.46 | 1.22 | 1.25 | 0.88 |
| Morocco | 0.99 | 0.38 | 0.54 | 0.71 | 1.96 |
| Netherlands | 0.71 | 0.48 | 0.57 | 0.80 | 1.20 |
| New Zealand | 0.76 | 0.77 | 0.74 | 0.36 | 1.71 |
| Nigeria | 1.34 | 1.03 | 2.76 | 0.18 | 13.76 |
| Norway | 0.66 | 0.54 | 0.59 | 1.13 | 1.43 |
| Pakistan | 1.07 | 1.68 | 1.94 | 0.71 | 1.42 |
| Peru | 4.92 | 0.37 | 1.24 | 0.46 | 2.10 |
| Poland | 0.79 | 0.39 | 0.90 | 2.01 | 0.94 |
| Portugal | 3.50 | 0.40 | 0.83 | 0.93 | 0.90 |
| Romania | 1.00 | 0.47 | 0.93 | 1.35 | 1.18 |
| RUSSIA | 0.92 | 0.58 | 0.82 | 1.00 | 0.62 |
| Saudi Arabia | 0.46 | 1.05 | 4.04 | 0.28 | 1.24 |
| Serbia | 1.29 | 0.66 | 1.10 | 1.26 | 1.40 |
| Singapore | 0.35 | 4.68 | 2.21 | 0.25 | 0.40 |
| Slovakia | 0.76 | 0.34 | 0.66 | 1.99 | 1.13 |

**Table 1** continued

| | BRAZIL | CHINA | INDIA | RUSSIA | S. AFRICA |
|---|---|---|---|---|---|
| Slovenia | 0.91 | 0.53 | 0.81 | 1.23 | 1.03 |
| SOUTH AFRICA | 1.08 | 0.50 | 1.70 | 0.62 | 1.00 |
| South Korea | 0.55 | 1.89 | 2.73 | 1.15 | 0.34 |
| Spain | 1.39 | 0.32 | 0.60 | 0.82 | 0.65 |
| Sweden | 0.66 | 0.68 | 0.66 | 1.13 | 1.00 |
| Switzerland | 0.67 | 0.39 | 0.69 | 0.97 | 0.93 |
| Taiwan | 0.60 | 2.44 | 2.13 | 1.13 | 0.67 |
| Thailand | 0.72 | 1.05 | 1.62 | 0.31 | 1.24 |
| Turkey | 0.90 | 0.48 | 1.09 | 0.95 | 1.14 |
| Uganda | 0.62 | 0.20 | 0.78 | 0.11 | 8.36 |
| Ukraine | 0.93 | 0.39 | 0.70 | 5.54 | 0.52 |
| United Kingdom | 0.86 | 0.81 | 0.87 | 0.71 | 1.48 |
| United States | 1.20 | 1.65 | 1.31 | 0.79 | 0.98 |
| Uruguay | 8.02 | 0.24 | 0.44 | 0.26 | 1.17 |
| Venezuela | 4.01 | 0.20 | 0.58 | 0.31 | 0.67 |
| Zimbabwe | 0.68 | 0.25 | 1.27 | 0.18 | 25.13 |

Results highlight instead the presence of different drivers of scientific collaborations (as measured by coauthorship) which nevertheless can't be considered a total novelty. Such drivers can be substantially grouped under three determinants. The first one is geography. That is, the strongest collaborations of BRICS countries are in many cases driven by "geographical proximity". It is the case for instance of Brazil. Table 3 shows that almost all PAIs above 2 in the Brazil's column are relative to collaborations with countries that are set in the same sub-continent (Latin America) and, in many cases (5 on 9 countries) are adjoined with the same country. The only country outside Latin America is Portugal: it is easy to remember that Brazil is a former Portuguese colony and that it is a Portuguese-speaking country.

This fact introduces the second and third drivers or collaboration as highlighted by our results. The first one of the two could be labelled "cultural proximity". It must be noted that in many cases it is difficult to disentangle "cultural proximity" from geographical proximity, as neighbourhood means often shared cultural background. This is particularly evident for instance in the cases of two of the three highest PAIs in our sample, those relative to the collaborations between China and Hong Kong and between South Africa and Zimbabwe.

The latter of the two, and the third one highlighted by our results is what could be called "historical proximity". This is present in the above described case of Brazil–Portugal collaboration, but it is even more evident in the case of Russia. 6 out of the 7 countries presenting the highest PAIs are former Soviet Republic. The seventh is Poland, which is again a former adjoined country of USSR and a former Warsaw Pact country. Nevertheless also in this case it is very difficult to disentangle this kind of proximity from the former two.

Other values of PAIs support our description of the drivers of scientific collaboration. In the case of China the other PAIs above 2 are those relative to the collaborations with Japan (geographic proximity), Singapore (geographic and—partly—cultural proximity) and Taiwan (geographic, cultural and—partly—historical proximity). In the case of South Africa, besides Zimbabwe, other three countries on five—Kenya, Nigeria and Uganda—are African countries (cultural and geographical proximity). The most blurred case on the five

**Table 2** Pattern of BRICS countries' scientific collaboration—PAIs, values >1

| | BRAZIL | | CHINA | | INDIA | | RUSSIA | | S. AFRICA |
|---|---|---|---|---|---|---|---|---|---|
| Argentina | 5.41 | Australia | 1.75 | Australia | 1.09 | Armenia | 2.77 | Argentina | 1.45 |
| Armenia | 1.60 | Canada | 1.25 | BRAZIL | 1.05 | Belarus | 5.36 | Armenia | 2.11 |
| Belarus | 1.38 | Hong Kong | 10.87 | Bulgaria | 1.19 | Bulgaria | 1.98 | Australia | 1.91 |
| Canada | 1.03 | Japan | 2.49 | Colombia | 1.26 | Croatia | 1.16 | Belarus | 1.35 |
| Chile | 3.11 | Malaysia | 1.14 | Croatia | 1.18 | Czech Republic | 1.78 | Belgium | 1.11 |
| Colombia | 4.21 | Nigeria | 1.03 | Egypt | 1.33 | Estonia | 1.71 | BRAZIL | 1.08 |
| Croatia | 1.07 | Pakistan | 1.68 | Georgia | 1.01 | Finland | 1.81 | Chile | 1.59 |
| Cuba | 6.35 | Saudi Arabia | 1.05 | Indonesia | 1.45 | France | 1.24 | Colombia | 1.24 |
| France | 1.25 | Singapore | 4.68 | Iran | 1.84 | Georgia | 2.35 | Cuba | 1.13 |
| Georgia | 1.57 | South Korea | 1.89 | Japan | 1.52 | Germany | 1.69 | Denmark | 1.02 |
| INDIA | 1.05 | Taiwan | 2.44 | Kazakhstan | 1.22 | Hungary | 1.16 | Georgia | 1.64 |
| Mexico | 2.27 | Thailand | 1.05 | Kenya | 1.28 | Israel | 1.24 | INDIA | 1.70 |
| Nigeria | 1.34 | United States | 1.65 | Malaysia | 5.55 | Italy | 1.05 | Iran | 1.03 |
| Pakistan | 1.07 | | | Mexico | 1.22 | Japan | 1.22 | Kenya | 8.32 |
| Peru | 4.92 | | | Nigeria | 2.76 | Kazakhstan | 9.72 | Morocco | 1.96 |
| Portugal | 3.50 | | | Pakistan | 1.94 | Latvia | 3.21 | Netherlands | 1.20 |
| Serbia | 1.29 | | | Peru | 1.24 | Lithuania | 1.65 | New Zealand | 1.71 |
| SOUTH AFRICA | 1.08 | | | Saudi Arabia | 4.04 | Mexico | 1.25 | Nigeria | 13.76 |
| Spain | 1.39 | | | Serbia | 1.10 | Norway | 1.13 | Norway | 1.43 |
| United States | 1.20 | | | Singapore | 2.21 | Poland | 2.01 | Pakistan | 1.42 |
| Uruguay | 8.02 | | | SOUTH AFRICA | 1.70 | Romania | 1.35 | Peru | 2.10 |
| Venezuela | 4.01 | | | South Korea | 2.73 | Serbia | 1.26 | Romania | 1.18 |
| | | | | Taiwan | 2.13 | Slovakia | 1.99 | Saudi Arabia | 1.24 |
| | | | | Thailand | 1.62 | Slovenia | 1.23 | Serbia | 1.40 |
| | | | | Turkey | 1.09 | South Korea | 1.15 | Slovakia | 1.13 |
| | | | | United States | 1.31 | Sweden | 1.13 | Slovenia | 1.03 |
| | | | | Zimbabwe | 1.27 | Taiwan | 1.13 | Thailand | 1.24 |
| | | | | | | Ukraine | 5.54 | Turkey | 1.14 |
| | | | | | | | | Uganda | 8.36 |
| | | | | | | | | United Kingdom | 1.48 |
| | | | | | | | | Uruguay | 1.17 |
| | | | | | | | | Zimbabwe | 25.13 |

**Table 3** Pattern of BRICS countries' scientific collaboration—PAIs, values >2

| | BRAZIL | | CHINA | | INDIA | | RUSSIA | | S. AFRICA |
|---|---|---|---|---|---|---|---|---|---|
| Argentina | 5.41 | Hong Kong | 10.87 | Malaysia | 5.55 | Armenia | 2.77 | Armenia | 2.11 |
| Chile | 3.11 | Japan | 2.49 | Nigeria | 2.76 | Belarus | 5.36 | Kenya | 8.32 |
| Colombia | 4.21 | Singapore | 4.68 | Saudi Arabia | 4.04 | Georgia | 2.35 | Nigeria | 13.76 |
| Cuba | 6.35 | Taiwan | 2.44 | Singapore | 2.21 | Kazakhstan | 9.72 | Peru | 2.10 |
| Mexico | 2.27 | | | South Korea | 2.73 | Latvia | 3.21 | Uganda | 8.36 |
| Peru | 4.92 | | | Taiwan | 2.13 | Poland | 2.01 | Zimbabwe | 25.13 |
| Portugal | 3.50 | | | | | Ukraine | 5.54 | | |
| Uruguay | 8.02 | | | | | | | | |
| Venezuela | 4.01 | | | | | | | | |

**Table 4** Pattern of BRICS countries' scientific collaboration—PAIs, values >5

| | BRAZIL | | CHINA | | INDIA | | RUSSIA | | S. AFRICA |
|---|---|---|---|---|---|---|---|---|---|
| Argentina | 5.41 | Hong Kong | 10.87 | Malaysia | 5.55 | Belarus | 5.36 | Kenya | 8.32 |
| Cuba | 6.35 | | | | | Kazakhstan | 9.72 | Nigeria | 13.76 |
| Uruguay | 8.02 | | | | | Ukraine | 5.54 | Uganda | 8.36 |
| | | | | | | | | Zimbabwe | 25.13 |

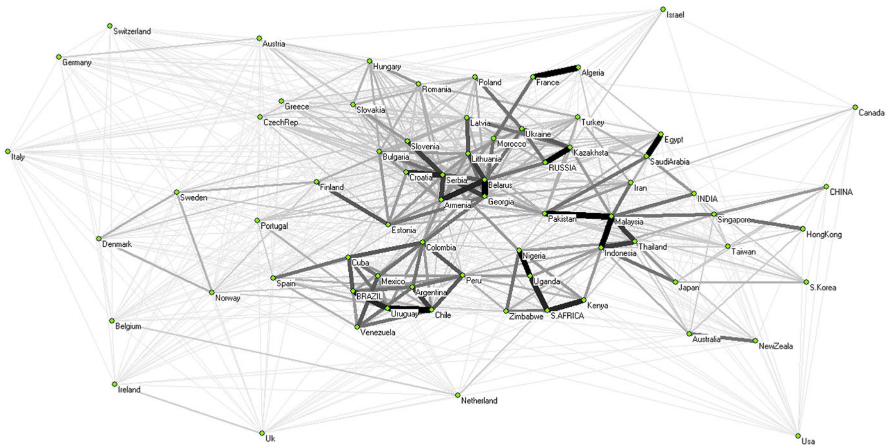


**Fig. 1** Network analysis—Full network

is that of India, showing loose geographical and/or cultural proximity (Malaysia, Saudi Arabia, Singapore, South Korea, Taiwan) while the case of Nigeria is more surprising.

Network analysis supports further these considerations. In particular Fig. 2 shows that—in the global picture built around BRICS countries—the strongest collaborations are driven by different combinations of the above highlighted drivers. For instance between France and Algeria the main driver is political (Algeria is a former French colony), but the two countries face one another across the Mediterranean sea. Saudi Arabia and Egypt share a common cultural background and are at close distance (though not adjoined). Kazakhstan is a former member of USSR and is adjoined to Russia (mix of political and geographical,

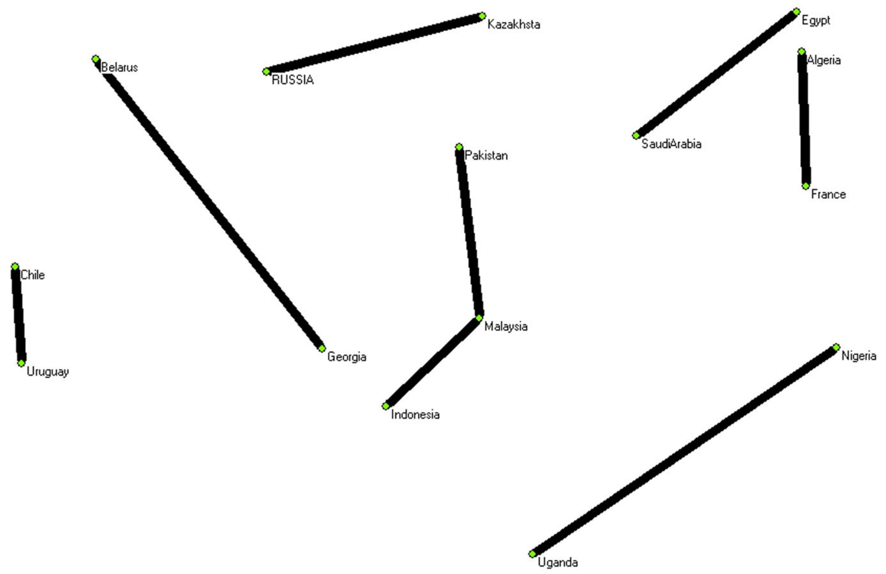


**Fig. 2** Network analysis—Normalized PAI values above 9

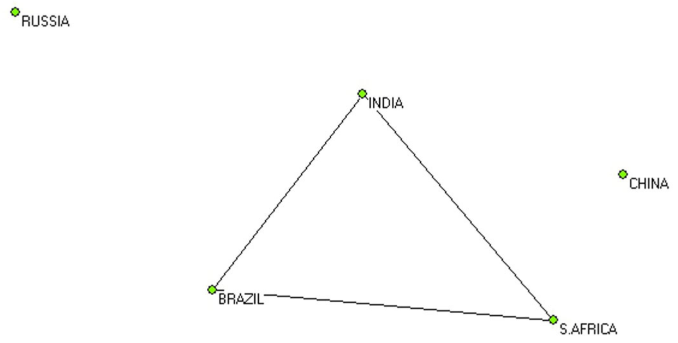


**Fig. 3** Network analysis—Intra-BRICS network

and possibly cultural driver). The same is true for Georgia and Belarus. Nigeria and Uganda, as well as Chile and Uruguay, are situated in the same Continent (respectively Africa and Latin America).

Finally, data tables highlight also the role of some "bridge country" that share strong (PAIs above 2) collaborations with two different BRIC countries. It is the case of Taiwan (with China and India), of Armenia (with Russia and South Africa), of Nigeria (with India and South Africa), of Peru (with Brazil and South Africa), of Singapore (with China and India).

## Conclusions

Aim of the present paper is the study of the pattern of scientific collaborations (measured via coautorship of scientific products) existing around the five BRICS countries: Brazil, Russia, India, China and South Africa. It tried to respond to the research questions on the structure of this pattern, on the relevance of inter-BRICS collaborations once measured in a wider context of collaborations, and thus on the weakness or strength of such collaborations. The topic is relevant under the point of view of the policy choices of the five BRICS countries. In fact, as described at the beginning of the present work, the BRICS are undertaking efforts in order to foster scientific collaboration among them, as witnessed by the documents cited above. The analysis performed in the present work integrates that of Finardi (2015) which discusses the relative strength of the inter-BRICS collaborations. In order to respond to the research questions the present work exploits Probabilistic Affinity Indexes, one of the probabilistic indexes. This index has the advantage of being totally independent from the absolute values of the collaborations, thus measuring their effective relative strength. The Indexes are calculated over a contingency table comprising 70 countries: the five BRICS plus 65 countries strongly collaborating (in terms of absolute values) with them.

Results show that the relative strength of inter-BRICS collaborations is very weak. The only collaborations above the PAI value of 1 are those in the Brazil–India–South Africa triad. Then, once the bar is slightly raised (PAI $> 2$) also these three links disappear.

This result indicates that it could be important to implement policies aimed at fostering the scientific collaborations between the five countries. As scientific research is generally considered a strategic asset for the growth of a country, improving collaborations between the five BRICS could have positive effects on their social and economic development. Moreover, as above introduced, BRICS aim at fostering mutual scientific collaboration, thus confirming its relevance. To this end it would be important for the BRICS to further promote policies and initiatives aimed at fostering collaboration in research. In fact above presented data show clearly that scientific collaboration in the network around BRICS countries has been driven basically by some main factors. These ones should be generally ascribed to geographical proximity, to a common cultural background and to historical reasons.

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