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Quantitative analysis for a better-focused international STI collaboration policy: A case of BRICS☆

Alexander Sokolov, Sergey Shashnov, Maxim Kotsemir*, Anna Grebenyuk

Institute for Statistical Studies and Economics of Knowledge, National Research University Higher School of Economics, Myasnitskaya Street 20, 101000 Moscow, Russian Federation

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ABSTRACT

International cooperation in science, technology and innovation (STI) plays an increasingly significant role as it allows one to gain access to new knowledge, increase national competitiveness, jointly respond to Grand Challenges, and contribute to overall bilateral and multilateral political cooperation. International alliances aim to establish a win-win system of common STI priorities in order to coordinate their research efforts in a wider political context. Within such a system, individual countries have to use different policy instruments for achieving their own benefits via STI collaboration with foreign partners. The paper addresses the following research question: "How can quantitative analysis help better identify priorities for STI collaboration that provide additional benefits for a country participating in such work?".

A set of common STI priorities for BRICS (Brazil, Russia, India, China, and South Africa) has been identified based on the analysis of strategic, Foresight, and STI policy documents and expert consultations. It includes a number of STI areas with a wide range of practical applications. Additional quantitative analysis shows how an individual member country can build its cooperation strategy by selecting particular thematic areas and relevant instruments for STI collaboration.

1. Introduction

Over the last several decades, research and development (R&D) activities have been increasingly characterized by larger scale work, interdisciplinary activity, global coverage and a greater role in innovation development. Despite the substantial growth of R&D expenditures in developing countries, none of them can conduct comprehensive research across the full range of subject areas. Accordingly, priority setting in STI becomes particularly important (which affect scientific and socio-economic development alike) both at the national level and within supranational alliances to combine efforts and complement one another's strengths. Therefore, the selection of a common system of STI cooperation priorities for a group of countries is an increasingly relevant objective.

Currently, the procedures and methods for setting STI priorities are most well developed at the national level and, to a lesser extent, for the bilateral cooperation of countries. Priority setting for a broader group of countries has not yet garnered a great amount of attention. Few exceptions generally relate to the practice of the selection of thematic or targeted priorities within the European framework programs.

The selection of science and technology (S&T) priorities for the European Union has been carried out on the basis of extensive consultations with the participation of expert groups representing leading European research institutions and other stakeholders (national S&T authorities, businesses, and civil society). After reaching a consensus, the priorities are further approved by the European Council. The agreed upon list of S&T priorities is then considered by program committees at a more detailed level and further implemented during R&D calls within annual working programs. The key role in this approach is played by interested stakeholders, whereas formal evidence-based methods are used to a limited extent. This creates some concerns: "Despite the emergence of new quantitative tools for evaluation, the conceptual underpinnings of priority setting remain quite weak and expert opinion continues to predominate in the evaluations used by policy makers to make policy decisions" (OECD, 2010).

This paper uses the methods of quantitative analysis for better focusing on the international STI collaboration policy of BRICS countries on the basis of a common system of STI priorities. For this purpose, the system of criteria for the selection of common priorities was proposed and the position of a particular country in the system of common

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* Corresponding author.
E-mail address: mkotsemir@hse.ru (M. Kotsemir).

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priorities assessed. This approach is applied to the case of BRICS countries. Despite the significant economic, social, institutional and other differences between them, in the presence of political will they demonstrate an ability to form S&T alliances, such as the BRICS framework program (started in 2016) covering several dozens of priority thematic areas (BRICS, 2016; BRICS, 2017).

The paper extends the existing practice and proposes a rather formalized approach to the selection of common STI priorities and reveals the strengths and weaknesses of each country in the system of common priorities. The proposed approach is illustrated by the case of BRICS countries, a consideration of each member state's strengths, and the drafting of a common S&T agenda relevant to all of them. The methods proposed envisage use of a wide range of information, which is compiled into the following composite indices: Index of Importance (of a specific thematic field for a BRICS country) and R&D Capacity Index (of a BRICS country in a specific thematic field).

It is assumed that the research alliances among three or more countries in areas characterized by high importance for all and the availability of complementary R&D capacities (determined on the basis of composite indices) may be accompanied by greater economic and social effects compared to bilateral cooperation. The approach used for identifying such areas is considered in more detail for the case of Russia by revealing thematic fields where the country is positioned as a) a leader among other BRICS countries, b) as an equal partner in potential research collaboration, or c) as a partner lagging behind. By using the aforementioned indices one can identify for its possible role in bilateral and multilateral research cooperation.

In accordance with the stated objectives, the article is structured as follows. Section 1 provides a literature review; Section 2 presents the methodological approach and a detailed description of the composite indices. Section 3 is devoted to the analysis and assessment of the system of common STI priorities for BRICS countries using the set of composite indices proposed in the methodological section.

2. Literature review

International STI cooperation has always been among the key priorities for national STI policies. It allows for coordinating the efforts of different countries in gaining new knowledge as such and achieving broader political benefits. There is clear evidence of the importance of STI collaboration: number of internationally authored publications has been steadily increasing and they are more frequently cited (see for example Aldieri et al., 2019; Edler, 2010b). The number of both bilateral and multilateral international STI projects has also been growing over recent decades.

There are numerous effects of STI collaboration like the contribution to the quality of science (through cross-fertilization, competition, combining complementary knowledge, access to world class researchers, facilities and groups), solving specific scientific problems that need input from various international teams, better access to funding and human resources (Boekholt et al., 2009), the development of the research capacity of universities (Graue et al., 2013; Kodama et al., 2012; Riahi et al., 2014; Stein et al., 2006; Sweileh et al., 2016), increasing research capacity and the performance of less developed countries (Chinchilla-Rodríguez et al., 2012 and 2018; Obamba and Mwema, 2009; Zdravkovic et al., 2016), and increasing the citation of publications and the visibility of research (Chuang and Ho, 2015; Fu et al., 2012; Gausia et al., 2015; Isiordia-Lachica et al., 2015; Khor and Yu, 2016; O'Leary et al., 2015; Olmeda-Gómez et al., 2009).

At the same time, each country strives to achieve its own interests in developing its S&T capacities, in STI collaboration in particular. The selection of STI priorities at the national level over the last two decades has been increasingly addressing strategic national or global problems (see Gokhberg et al., 2016). Whereas the first traditional (based on industrial policy priorities) and system-oriented approaches corresponded to linear and network innovation development models, the later target-oriented one belongs to the so-called societal challenges model and tries to meet social and economic challenges. These approaches are related to the application of Foresight tools for the prioritization of research and innovation policy and strategy (see Georghiou and Harper, 2011).

There are numerous studies related to policy tools for STI collaboration. Figueroa and Stamm (2012) provide the overview of policy tools for the stimulation of effective international STI collaboration. Serger and Wise (2010) and Varum and Piscitello (2011) analyze the policy tools for the internationalization of STI. Georghiou (2001) highlights key points for evolving a common European framework of S&T cooperation policy. Edler (2010a) analyzes challenges that are relevant for international S&T policy in European countries and later on (Edler, 2010b) provides an overview of the efforts of countries on the coordination of their policies on S&T collaboration. Tõnurist and Kattel (2016) perform a similar analysis for a set of Nordic countries. Schuch et al. (2012) analyze policies for S&T collaboration among EU, Eastern European, and Central Asian countries.

There are a number of motivations behind the internationalization of STI policy (Edler and Flanagan, 2011): wider access to scientific knowledge, more effective and efficient knowledge generation and transfer, indirect contribution to the attractiveness and innovation dynamics of a country, responding to global challenges, promoting political cooperation, dialogue, trust and aid for developing countries, and developing S&T human resources (e.g., via talent seeking, brain circulation, securing adequate supply of manpower for S&T).

Usually the following three types of STI priorities are considered (see e.g. Drilhon, 1991; Gassler et al., 2004; Haegeman et al., 2013; OECD, 2010): thematic priorities (related to specific fields of S&T); mission-oriented priorities (related to specific socio-economic or technological goals); and functional priorities (related to characteristics of the national science and innovation system).

Currently the most substantial experience in setting thematic STI priorities of various types has been accumulated at the national level. The first such work were initiated in the USA, where critical technologies were considered priorities. The “critical level” of specific technologies was linked to their characteristics including their importance to a wide range of industries, the scope for application in integrated systems, and their potential contribution to solving national social problems (Popper et al., 1998). The French “100 Key Technologies” were supposed to “give France a competitive edge and increase the country's appeal in the next 5-10 years” (Ministère de l'Economie, des Finances et de l'Industrie, 2006).

Further, along with critical technologies, lists of the most important thematic S&T areas were often considered priorities. The Scandinavian Research Program priority setting (Salo and Liesiö, 2006) used such criteria as novelty and potential contribution to increasing industry's competitiveness, producing desirable social and environmental effects and practicality including researchers' competitiveness and the potential for the application of created R&D. Denmark's S&T priorities were expected to contribute to dealing with major social problems and at the same time (through R&D investments) serve as a driver of economic growth, employment, and wellbeing (Danish Ministry of Higher Education, 2015).

There are numerous examples of studies on the application of Foresight tools for STI priority setting, both for individual countries: UK (Georghiou, 1996); Germany (Cuhls, 2004); Japan (Kuwahara et al., 2008); Republic of Korea (Choi and Choi, 2015); and comparisons of several countries: Great Britain, Australia and New Zealand (Martin and Johnston, 1999); Kazakhstan, Romania, and Vietnam (da Fonseca, 2016).

Approaches based on the Foresight methodology also play a major role in STI priority setting activities in all BRICS countries (see Cagnin, 2014; Chan and Daim, 2012; Li, 2009; Pouris and Raphasha, 2015; Shashnov and Poznyak, 2011; Shashnov and Sokolova, 2013; Sokolov and Chulok, 2016). A brief overview of key national Foresight projects implemented in the BRICS countries in recent years is given in Appendix, Table A.1. At the same time, there are only a few examples of studies dealing with priorities of international S&T cooperation for BRICS members with other countries (see e.g. Penalva, 2008 for Brazil; Mojica, 2010 for Latin America; Kotsemir et al., 2015; Sokolov and Chulok, 2016 for Russia; Li et al., 2017; Gabriel and Schmelcher, 2018 for China).

Joint priorities in international S&T cooperation can be set up in a wide range of forms (Haegeman et al., 2015). They might be focused on thematic areas or structural problems (e.g. human resources, infrastructure, knowledge transfer, etc.) or grand challenges; particular or diverse, conventional or emerging research areas; basic or applied research; short-term or longer-term agenda. The selection of priorities can be user-based (driven by users' needs), institutional (driven by researchers), or political (driven by broader policy choices).

Over the last two decades, methodologies and mechanisms for setting and implementing international-level priorities have been increasingly focused on new challenges reflecting global development trends. Studies aimed at assessing STI development prospects, designing approaches to priority setting, and implementing relevant strategies also play a major role in the EU (European Forum on Forward Looking Activities, 2015a, 2015b) and OECD (OECD, 2010, 2012). Such priorities are set in the framework of designing long-term strategies for the sustainable socioeconomic development of specific countries, and major supranational alliances, based on the multilateral assessment and optimization of their possible contribution to development and competitiveness (European Commission, 2018a; OECD, 2016). In recent years, such approaches were commonly applied in many countries and, to a lesser extent, in international alliances.

A significant contribution to the development of approaches to common priority setting was made by the European Union in the scope of designing and implementing a series of its framework programs (BILAT-USA, 2010). Since 2014, the European Union has been implementing the Horizon 2020[1] framework program. Priority there has been given to several high-performance technologies including environmental, nano-, bio-, and information technologies oriented towards solving key socioeconomic problems (such as green energy, transport, climate change, and an ageing population). Foresight was a key tool for preparing the Horizon 2020. The program's priorities were based on the results of broad (and focused) Foresight projects covering more important S&T development areas, in specific European countries and on the EU level generally.

Horizon Europe, the next framework program for research and innovation (2021–2027) and the system of its priorities are also developed based on the Foresight methodology. The BOHEMIA ("Beyond the Horizon: Foresight in Support of the Preparation of the European Union's Future Policy in Research and Innovation") project supports current discussions on future European R&D policy informing interested stakeholders about the needs and opportunities for research and innovation development in Europe (see Weber et al., 2018). The EU has also accumulated experience in the Foresight-based identification of STI cooperation priorities with other countries (see, for example, Guy, 2007 and Haegeman et al., 2015). Particular attention in this process has been paid to addressing grand challenges (Carraz, 2012; Stamm et al., 2012).

Selected priorities focus on strategic socioeconomic and S&T development issues. To make sure these issues are adequately covered, relevant stakeholders are involved in priority setting including the public authorities, businesses, and the academic community. A broad circle of experts also participates in priority setting, actively applying various quantitative and qualitative analytical techniques (see Miles et al., 2017; Saritas and Anim, 2017; Sokolov, 2013 for the overview of Foresight methods). The application of the aforementioned approaches results in lists of priority areas and critical technologies as well as long-term S&T development Foresight reports.

In the academic literature, studies focusing on the measuring and quantification of STI collaboration policy and the internationalization of research can be highlighted. Edler (2008) provides indicators for the support of international STI collaboration policy. Further, Edler and Flanagan (2011) discuss the indicators that can be used to measure the internationalization of research policy. In a similar way, various indicators are developed for the quantification of the internationalization of funding agencies (Cunha-Melo, 2015); the quantification of the opening of national research programs – policy tools that support international collaboration (Primeri et al., 2014 and further Primeri, 2015).

To assess the level of economic and STI development of countries, a number of global indices were developed – e.g. Global Competitiveness Index from the World Economic Forum (Schwab, 2018); Global Innovation Index developed by INSEAD in cooperation with Cornell University and the World Intellectual Property Organization (Dutta et al., 2018); European Innovation Scoreboard from the European Union (European Commission, 2018b, 2018c); and the ICT Development Index by the International Telecommunication Union (International Telecommunication Union, 2018).

In this paper, composite indices are proposed that further develop the approach to the selection of S&T cooperation priorities on the basis of scientific specialization indices earlier developed by the authors (see Shashnov and Kotsemir, 2018; Sokolov et al., 2017).

3. Methodology

The methodology used in the research covers the following major steps: the identification of common STI priorities for BRICS member states; a quantitative analysis of the identified priorities based on a system of integral (composite) indices; and the identification of thematic research areas and relevant cooperation instruments able to bring benefits to a particular country within the framework of the multilateral cooperation (see Fig. 1).

3.1. Identification of STI priorities

The identification of common STI priorities for a group of countries should pursue the most important socioeconomic development objectives shared by all countries, mitigating problems related to grand challenges, and utilize synergies of available competitive advantages (such as S&T capacities, available resources, etc.).

For the case of BRICS countries, the following basic methodological assumptions were applied:

- designing a *common system of thematic and functional priorities* must consider key socioeconomic development issues, relevant to all countries in the group;
- priorities should be selected in a limited number of S&T areas to concentrate available resources on;
- priorities should be considered for the same time horizon, typically 10 years;
- efficient STI policy tools should support the implementation of priorities.

These assumptions are applied via a system of criteria, the most important of which include the following:

- the relevance of thematic priority areas for the country's development, in particular:
  - economic growth (increased competitiveness in domestic and international markets, relevance for several industries and interdisciplinary S&T areas, job creation, etc.);

[1] See more details on: http://ec.europa.eu/research/horizon2020/index_en.cfm?pg=h2020.

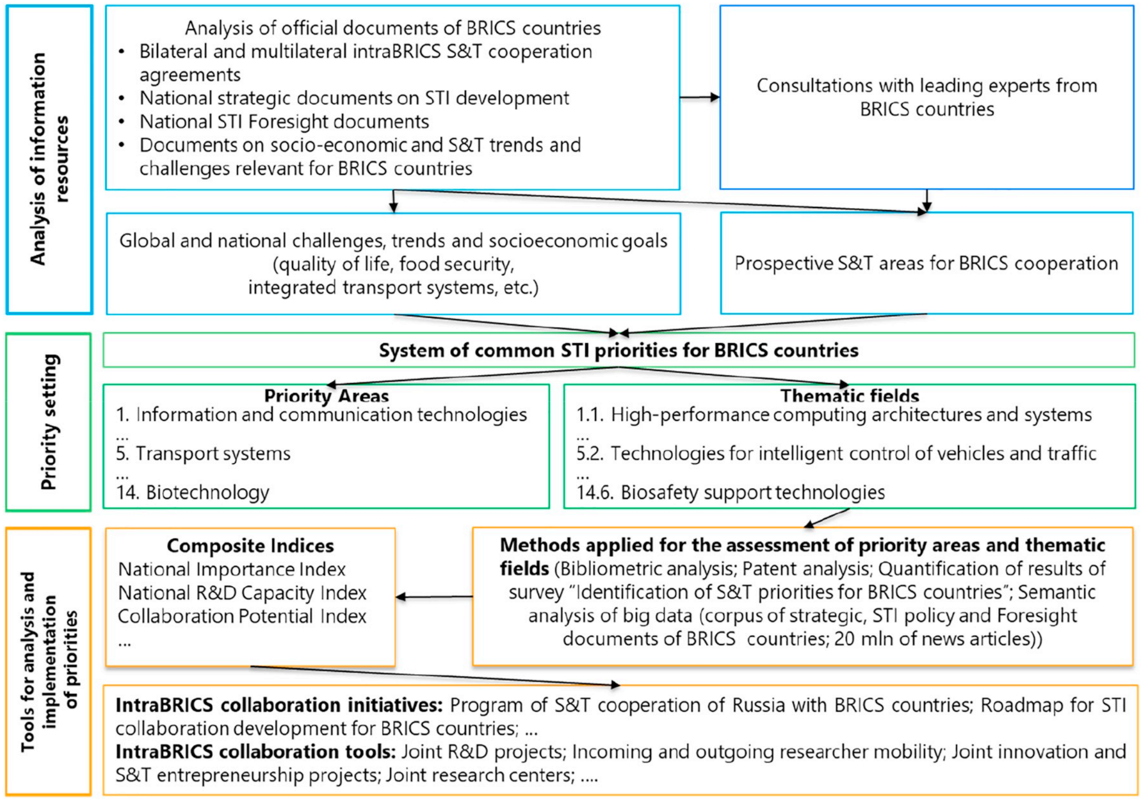

Fig. 1. General layout for the identification and analysis of common of STI priorities for BRICS countries.

  - social development (resolving the most acute social problems);
  - technological development.
- the availability of resources for the practical implementation of priorities, in particular:
  - financial resources;
  - human resources;
  - S&T capacities;
  - relevant manufacturing basis.

This approach implies the analysis and compilation of goals and objectives set in official international and national strategic, Foresight, and STI policy documents adopted by the member countries with an assessment of their S&T capacities and the opinions of expert communities in all relevant countries, therefore, the following methods were used to select the priorities:

- an analysis of documents;
- consultations with experts from BRICS countries.

At the first stage, more than 150 strategic, Foresight and STI policy documents of BRICS countries were selected, which set out R&D areas of particular importance for national development and S&T cooperation, including:

- strategic national documents on BRICS countries' STI development: plans, programs, strategies, missions, visions, roadmaps, initiatives, priority lists (66 documents);
- Foresight studies envisioning BRICS countries' STI development prospects (16 documents);
- other documents describing socioeconomic and S&T trends and challenges relevant for BRICS countries (52 documents);
- BRICS countries' official documents related to STI cooperation (23 documents).

At the second stage, these documents were analyzed to derive the key socioeconomic goals declared by individual countries and thematic STI areas considered as national STI priorities. As a result of the analysis and "processing" of strategic, Foresight and STI policy documents of BRICS countries, the corpus of STI areas (like "Aerospace and defence industry"; "Marine technology"; "Laser technology"; "Ecology"; "Transport"; "Healthcare", etc.) were identified, which would contribute to accomplishing common socioeconomic, S&T, and innovation development objectives (see Table A.2 in the Appendix for the examples of STI areas that were derived from various documents of BRICS countries). This corpus of STI areas presents relevant priorities in the original documents on bilateral and multilateral cooperation. The documents were analyzed to identify relevant thematic and functional priorities. The synthesis and aggregation of the corpus of STI areas produced a list of major common S&T development areas for BRICS countries, reflecting all the key S&T areas currently being promoted by two or more BRICS countries in line with the criteria adopted for their selection (see Table A.3 in the Appendix for the results of this synthesis and aggregation).

The resulting list of S&T development thematic areas relevant for BRICS countries was validated and adjusted during consultations with experts from BRICS countries, whose research interests are related to the selected thematic areas through face-to-face personal interviews using the VOIP technique (i.e. Skype call, voice call, video conference etc.). Expert consultations were conducted to validate the preliminary lists of priorities and thematic areas, as well as to collect data on the importance of the selected areas as well as their S&T potential. As a result, the final list of STI priorities for BRICS countries was drafted on the basis of "processing" strategic, Foresight, and STI policy documents followed by validation though expert consultations and included 14 priority areas. The selected priority areas have been further considered as common STI priorities for all BRICS countries. Within the 14 priority areas, particular thematic fields have been selected, which were most relevant to the identified socioeconomic objectives were selected. For each priority area, four to seven such thematic fields were found. In total, we identified 74 thematic fields within 14 priority areas.

3.2. Assessment of the selected system of priorities

For a comprehensive assessment of the identified common priority areas (and thematic fields), three integral (composite) indices were developed. They encompass data on the R&D capacities of BRICS countries and the importance of the selected priority areas and thematic fields:

- bibliometric and patent analysis (see Box A.1, Appendix for details);
- big data analysis (search for keywords related to thematic areas in the texts of news articles in a database of professional media information sources (nearly 20million items were indexed at the moment of analysis (December 2017)[2]) and the texts of more than 70[3] English-language strategic, Foresight and STI policy documents of BRICS countries. See Box A.2, Appendix for details);
- the results of a web-based expert survey "Identification of S&T priorities for BRICS countries" (877 respondents from BRICS countries participated by filling out a questionnaire online. See Box A.3 for the details of survey and Box A.4 for the questionnaire of the survey).

The analysis used several composite indices that characterize the importance of a certain thematic field for BRICS countries as well as their research capacity (both individually and in comparison with other BRICS countries).

For all 74 thematic fields four indices were developed:

- National Index of Importance (of a specific thematic field) (NII);
- Integrated BRICS Importance Index;
- National R&D Capacity Index (in specific thematic field) (NRDCI);
- Russia's R&D Capacity Index vs. other BRICS countries.

To calculate the values of these indices, different sources of data were used. Indices for priority areas are calculated as simple average of values of indices for all thematic fields included in a specific priority area.

The **National Index of Importance (of a specific thematic field) (NII)** is based on the quantification of answers by respondents posed the following: "Estimate the importance of thematic fields of priority area for your country". This question could be answered: "Very high"; "High"; "Medium"; "Low"; "Very low". This index has a range of 0.00 (the specific thematic field is not important at all for a specific BRICS country) and 1.00 (this field is of critical importance for BRICS countries). Formula for the calculation on National Index of Importance is provided in Eq. (1) in Box A.5, Appendix.

For an analysis of the importance of the studied thematic fields and priority areas for all BRICS countries in total, an Integrated BRICS Importance Index was developed. It encompasses National Indices of Importance of all BRICS as well as big data analysis (the semantic processing of texts of news articles and strategic, Foresight and STI policy documents of BRICS countries).

The **Integrated BRICS Importance Index** ranges between 0.00 (specific thematic field is not important at all for BRICS countries) and 1.00 (field is of critical importance for BRICS countries), and is calculated on the basis of the following (see Eq. (2) in Box. A.5, Appendix for the formula):

- data on the average values of National Indices of Importance for all BRICS countries;
- data on keywords related to the thematic field in news articles indexed in databases of media information sources covering more than 2700 media sources (more than 20million news articles indexed in the database were processed);
- data on keywords related to a specific thematic field in English-language strategic, Foresight, and STI policy documents of BRICS countries (more than 70 documents were processed).

The **National R&D Capacity Index** (NRDCI) is an integral measure for the research potential of BRICS countries. Its calculation is based on the information from:

- the results of a survey (the quantification of answers from respondents to the questions "Estimate the S&T capability of your country vis-a-vis leading countries in the thematic fields of the selected priority area" (Research Leadership Index) and "For the thematic fields of the selected priority area, please select no more than two BRICS countries that are most promising for scientific collaboration" (Collaboration Potential Index));
- bibliometric analysis (Category Normalized Citation Impact (CNCI) indicator and Relative Comparative Advantages Index (RCA) or an index of scientific specialization);
- patent analysis (Relative Technological Advantages Index (RTA) or an index of technological specialization).

The formula for the calculation National R&D Capacity Index is provided in Eq. (3) in Box A.5, Appendix. The values of NRDCI varies from between 0.00 (no R&D capacity of BRICS country in the specific thematic area) and 1.00 (greatest R&D capacity of a BRICS country in a specific thematic field). The formulas for the calculation of the components of national R&D are presented in Eqs. (6)–(9) in Box A.5, Appendix.

Russia's R&D Capacity Index vs. Other BRICS Countries compares Russia and BRICS countries with the maximum and minimum values on National R&D Capacity Index for a specific thematic field. The formula for the calculation of this index is provided in Eq. (4) in Box A.5, Appendix.

The National Index of Importance and National R&D Capacity Index were used for plotting country profiles by selected thematic fields based on their importance for the country and the country's R&D capacity related to these fields (see Fig. 2 for an illustrative scheme and Fig. 3 for the profiles of BRICS countries). The concentration of bubbles of different colors (representing specific thematic fields for different priority areas) in the upper right quadrant means strong R&D capacities in different thematic fields and their high importance for the country. On the contrary, the concentration of bubbles in the lower left quadrant shows relatively low R&D capacities. The integrated BRICS Importance Index and Russia's R&D Capacity Index vs. Other BRICS Countries were then used to identify the possible role of Russia in bilateral and multilateral research cooperation with other BRICS countries. The proposed approach helps to identify thematic fields where Russia is positioned as a leader among other BRICS countries, an equal partner in potential research collaboration, or as a partner lagging behind (see Fig. 2 for an illustrative scheme and Fig. 7 for the application this approach to Russia).

4. Results

4.1. System of common STI priorities for BRICS countries

According to the methodology described in Section 2, a system of

[2] When running the semantic processing of news articles, the whole corpus of news articles (20million items indexed at December 2017) was processed for keywords related to the studied system of thematic fields.

[3] 72 English-language documents were selected for semantic processing from the initial corpus of 157 strategic, Foresight, and STI policy documents of BRICS countries in English, Russian, Chinese, and Portuguese used for the formation of the system of common STI priorities for BRICS countries.

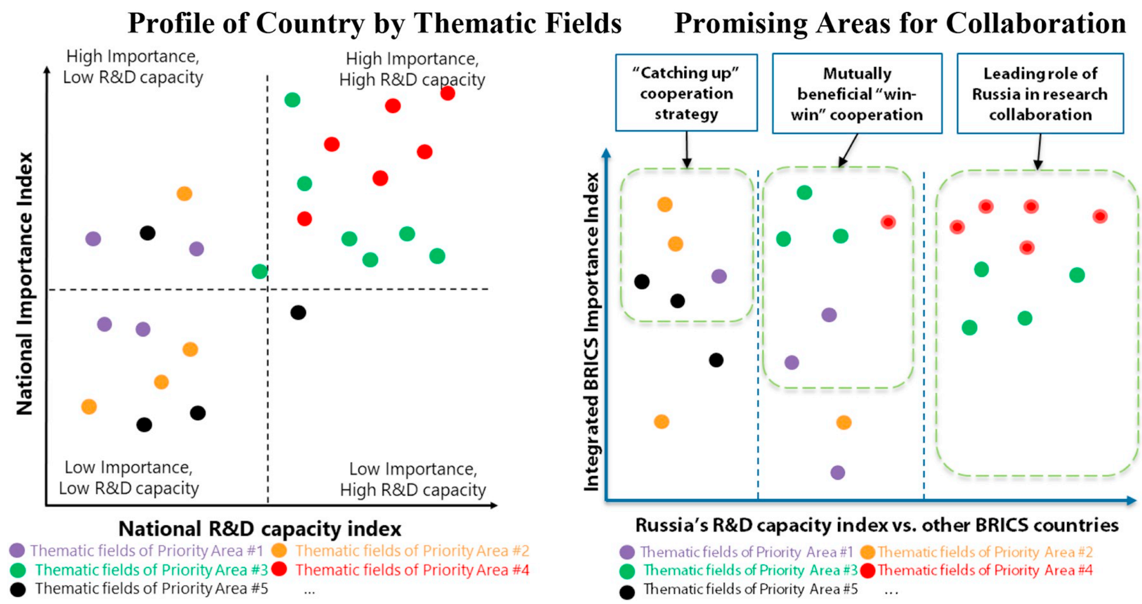

Fig. 2. Illustrative scheme of the identification of promising areas of bilateral cooperation between Russia and other BRICS countries.

common STI priorities for BRICS countries was formed. It covers 14 priority areas and 74 thematic fields (see Table 1). They largely reflect the mainstream areas for global S&T development, although some areas such as nuclear energy, sustainable agriculture, and a few others have been given particular importance in BRICS countries.

4.2. Analysis of indices

Fig. 3 illustrates the profiles of BRICS countries in terms of the National R&D Capacity Index and National Index of Importance for 74 thematic fields within 14 priority areas.

The analysis of Fig. 3 shows that the Brazilian profile is biased towards low R&D capacity. For all 74 thematic fields in Brazil, the value of NRDCI is below 0.75. In Russia, all thematic fields receive values on the NII higher than 0.5. More than half of the thematic fields in Russia have low values of NRDCI between 0.25 and 0.5. In some thematic fields Russia has a value of NRDCI higher than 0.75 (primarily in "Space systems and astronomical observations" and "Nuclear energy" priority areas). In India, many thematic fields are concentrated in the zone of high importance and strong R&D capacity. All thematic fields except the thematic fields for "Climate change, environmental protection and disaster management have importance scores higher than 0.5. In several thematic fields India has NRDCI values far below 0.4. The profile of China is similar to India but the bias towards strong R&D capacity in all thematic fields is even more than in India. In China, almost all thematic fields have an NRDCI value higher than 0.5.

Fig. 4 shows the values of National Index of Importance (NII) and National R&D Capacity Index (NRDCI) for all BRICS countries for the 14 selected priority areas. It aggregates the profiles of BRICS countries presented on Fig. 3. The values of these indices are considered proxy indicators reflecting the research interests and specializations of BRICS countries: particular areas can be referred to as priorities if both indices are higher than 0.5. On average, for all 14 priority areas these values exceed that threshold, though for some countries and some areas this is not true. In general, for all BRICS counties, respondents selected "Information and communication technologies" and "Search, exploration, development and mining of minerals" as the most important. On the other hand, "Climate change, environmental protection and disaster management" received the lowest average scores from respondents from all BRICS countries except South Africa. BRICS countries have strong R&D capacities in all priority areas. The average (among BRICS countries) value of NRDCI varies from 0.509 points for "Nuclear energy" to 0.611 for "Water resources". China has strong R&D capacities in all priority areas. For all priority areas the value of NRDCI Capacity Index is higher than 0.6. China has the highest values for this index among BRICS countries in many priority areas. The average value of NRDCI among all 14 priority areas in China is 0.701 – the highest level among all BRICS countries. On the contrary, Brazil in general has low (compared to other BRICS countries) levels of NRDCI for many priority areas. The average value of NRDCI for Brazil is 0.441 – the lowest value among BRICS countries.

The quantification of results from the web-based expert survey "Identification of S&T priorities for BRICS countries" (877 respondents from BRICS countries) was used for the calculation of the National Index of Importance and National R&D Capacity Index. Therefore, an analysis of the responses of experts from BRICS countries to some survey questions can help one understand the formation of composite indices. Quantified responses to the question "Estimate the importance of thematic fields of the selected priority area for your country" served as the basis for the calculation of National Index of Importance. Fig. 5 shows the distribution of responses of experts from BRIC countries to this question. "High" and "Very high" options dominate for almost every priority area except "Climate change, environmental protection, and disaster management". Only 1.6% (on average) respondents from BRICS countries marked the importance of this priority area as "very high". For all other priority areas except "Renewable energy resources", the shares of "Very High" responses were higher than 35%. Also "Climate change, environmental protection, and disaster management" priority area received the highest shares of "very low" and "low" answers. As a result, this priority area has the lowest (in average for all BRICS) value of National Index of importance, far behind all other priority area.

The quantification of the answers of respondents to the question "Estimate S&T capability of your country vis-a-vis leading countries in thematic fields of the selected priority area" was used for the calculation of the National R&D Capacity Index (NRDCI). Fig. 6 shows the distribution of answers by Russian respondents to this question and the value of NRDCI.

According to the Russian respondents, "Nuclear energy" is the area where the country has the strongest R&D capacities. The share of

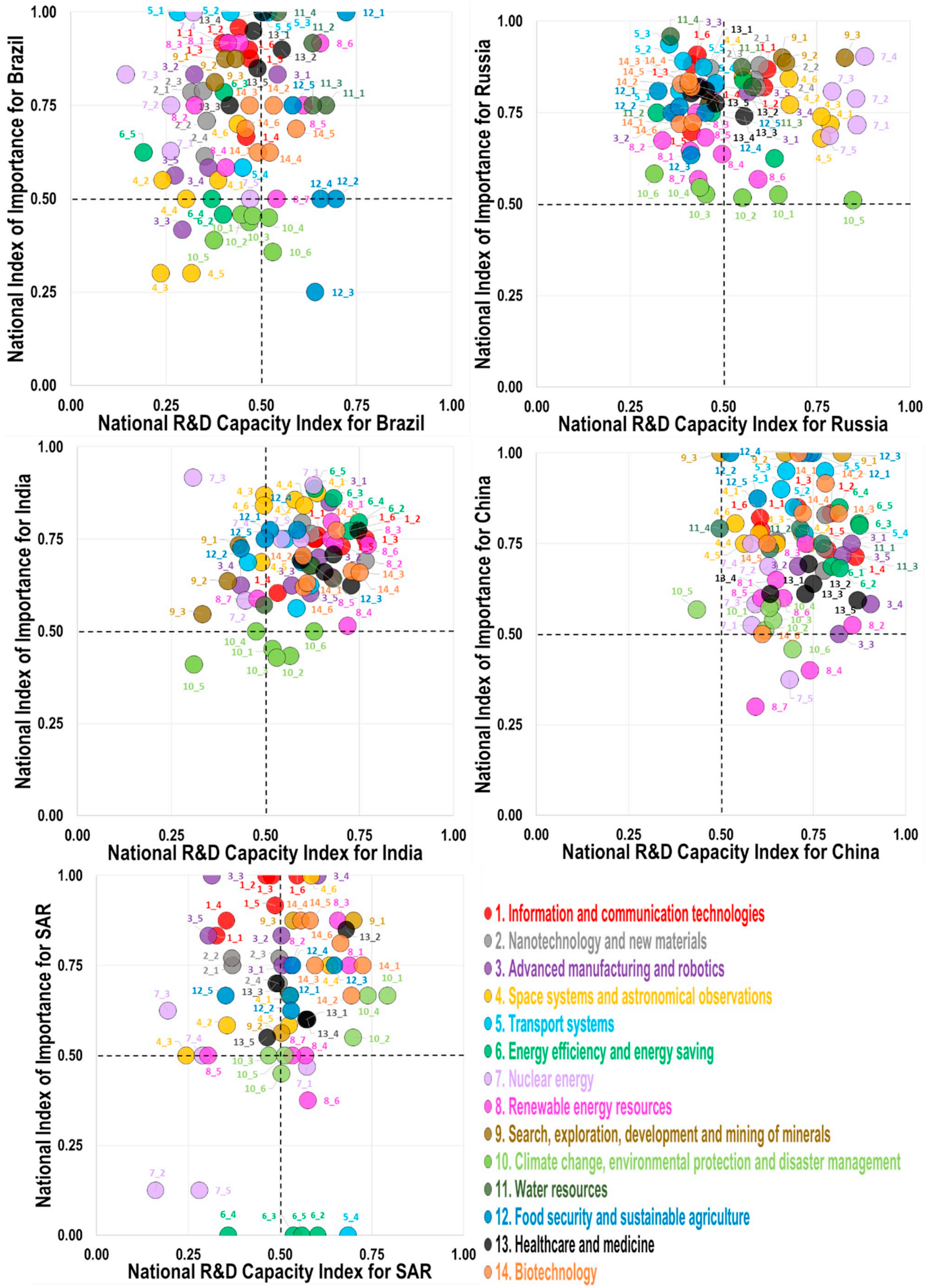

Fig. 3. Profiles of BRICS countries by the values of National Index of Importance and National R&D Capacity Index for 74 thematic fields.
Source: Authors' calculations.

Table 1
Common STI priorities for BRICS identified on the basis of their strategic, foresight, and STI policy documents.

Priority areas	Thematic fields within priority areas
1. Information and communication technologies	1.1. High-performance computing architecture and systems. 1.2. High-speed data transmission technologies and communication infrastructure. 1.3. Artificial intelligence technologies, data analysis technologies, data processing technologies. 1.4. Human-machine interaction technologies, neurotechnologies, cognitive technologies. 1.5. Technologies for the creation of intelligent control systems and smart infrastructure, machine-machine interaction technologies; Internet of Things. *1.6.* Information security technologies.
2. Nanotechnology and new materials	2.1. Technologies for manufacturing, processing, and diagnostics of functional materials. 2.2. Technologies for manufacturing, processing and diagnostics of structural materials. 2.3. Technologies for manufacturing, processing and diagnostics of hybrid materials, biomimetic materials and medical materials. 2.4. Computer technologies for material design and modeling.
3. Advanced manufacturing and robotics	3.1. Computer technologies for design, mathematical modeling, engineering analysis, and optimization of structures and processes. 3.2. Technologies for the management of production processes, life cycle of products; including technologies for the creation and use of sensory systems. 3.3. Additive technologies, laser technologies and other production technologies. 3.4. Technologies for creating robotic tools and systems. 3.5. Photonics, new element base technologies, electronic devices technologies, quantum technologies.
4. Space systems and astronomical observations	4.1. Technologies for applying the results of space activities; geospatial technologies. 4.2. Technologies for creating prospective spacecraft, unified satellite platforms, including technologies for creating their component base. 4.3. Technologies and control systems for space vehicles and systems. 4.4. Technologies for creating target equipment for space and Earth observation at various ranges of the electromagnetic spectrum. 4.5. Technologies for reducing possible negative effects of space activities and threats to the safety of life on Earth from celestial bodies. 4.6. Astronomical observations.
5. Transport systems	5.1. Technologies for high-speed transportation of passengers and cargo. 5.2. Technologies for intelligent control of vehicles and traffic. 5.3. Transport security technologies. 5.4. Technologies for the creation of environmentally friendly and energy efficient transport. 5.5. Technologies for transport infrastructure creation.
6. Energy efficiency and energy saving	6.1. Clean heat generation technologies. 6.2. Smart technologies and systems for demand-side management. 6.3. Efficient energy transfer technologies. 6.4. Technologies for creating new light sources and intelligent lighting systems. 6.5. Energy storage technologies.
7. Nuclear energy	7.1. Technologies for advanced nuclear reactors. 7.2. Technologies for closing the nuclear fuel cycle of fast neutron reactors. 7.3. Technologies for small and medium power reactors. 7.4. Spent nuclear waste storage and utilization technologies. 7.5. Technological bases for controlled thermonuclear fusion for power engineering.
8. Renewable energy resources	8.1. Prospective technologies for converting wind energy into electrical energy. 8.2. Prospective technologies for converting solar energy into electrical energy. 8.3. Technologies for the combined use of energy from several renewable sources. 8.4. Prospective technologies for using of low-potential heat of natural environments. 8.5. Energy biomass production and processing technologies. 8.6. Highly efficient technologies for converting mechanical energy of a water stream into electrical energy. 8.7. Sea and ocean energy use technologies.
9. Search, exploration, development and mining of minerals	9.1. GIS (geologic information system) technologies for natural resource extraction. 9.2. Technologies for the complex development of hydrocarbon deposits and other minerals. 9.3. Technologies for the development and extraction of mineral resources in areas characterized by extreme natural and climatic conditions (the Arctic shelf, the World Ocean, etc.).
10. Climate change, environmental protection and disaster management	10.1. Climate change and extreme climatic events forecasting technologies. 10.2. Technologies for monitoring the state of the environment and early detection and prediction of natural emergencies. 10.3. Technologies for reducing the risk and consequences of natural and manmade disasters. 10.4. Technologies for maintaining of a favorable environment and ensuring environmental safety. 10.5. Technologies for ensuring integrated safety of operations on the continental shelf of the Russian Federation, the Arctic, and Antarctic. 10.6. Waste processing technologies.
11. Water resources	11.1. Technologies for water quality monitoring in natural water bodies, restoration of water quality and hydroecosystems. 11.2. Water purification and treatment technologies. 11.3. Flood risk forecasting and management technologies. 11.4. Technologies for integrated water resources management, including closed-cycle technologies. 11.5. Technologies for the development and use of resources of the World Ocean.
12. Food security and sustainable agriculture	12.1. Agrotechnologies for plant breeding. 12.2. Agrotechnologies for stock-breeding. 12.3. Agrotechnologies for fisheries. 12.4. Agrotechnologies for food industry. 12.5. General-purpose agrotechnologies.
13. Healthcare and medicine	13.1. Cellular and bioengineering technologies, tissue engineering. 13.2. Molecular profiling and diagnostics. 13.3. Monitoring and control functions for organs and systems. 13.4. Technologies for experimental modeling and creation of new medicines. 13.5. Information technologies for biomedical applications; medical robotics. 13.6. Neurotechnologies.
14. Biotechnology	14.1. Synthetic Biology. 14.2. Genomic and epigenetic technologies. 14.3 Cell biotechnology. 14.4. Biosynthetic and biocatalytic technologies. 14.5. Technologies for biomaterials and industrial biotechnology. 14.6. Biosafety Support Technologies.

respondents who marked the R&D capacity of Russia as “At the cutting edge” was 71.2%, much higher than for all other priority areas. These assessments of Russia's S&T capabilities in this priority area by respondents correlate with its highest (among all priority areas) value of National R&D Capacity Index. Another area of quite strong S&T capability of Russia according to respondents is “Information and communication technologies”. Respondents consider “Food security and sustainable agriculture” as a priority area with the lowest S&T capacity of Russia. This statement by respondents correlates with the lowest value of NRDCI for this priority area. The other priority areas that were assessed by respondents as areas of low S&T capability are: “Healthcare and medicine”, “Water resources”, and “Renewable energy resources”.

4.3. Promising modes of collaboration for Russia with other BRICS countries

The comparison of Russia's R&D capacity with other BRICS countries allows one to distinguish three major groups of thematic fields with different prospects for research collaboration:

- BRICS countries lag behind Russia in a priority area: Russia can play a leading role in collaboration;
- Russia and other BRICS countries have comparable levels of R&D capacity: mutually beneficial “win-win” cooperation;
- Russia lags behind BRICS countries in a priority area: “catching up” cooperation strategy.

Priority area	National Index of Importance						National R&D Capacity Index					
	Brazil	Russia	India	China	SAR	Aver.	Brazil	Russia	India	China	SAR	Aver.
1. Information and communication technologies	0.872	0.825	0.724	0.790	0.938	**0.830**	0.442	0.491	0.651	0.729	0.442	**0.551**
2. Nanotechnology and new materials	0.724	0.852	0.754	0.750	0.748	**0.765**	0.343	0.559	0.644	0.748	0.434	**0.546**
3. Advanced manufacturing and robotics	0.646	0.803	0.681	0.648	0.883	**0.732**	0.359	0.455	0.587	0.823	0.446	**0.534**
4. Space systems and astronomical observations	0.483	0.766	0.828	0.769	0.681	**0.705**	0.320	0.703	0.550	0.635	0.478	**0.537**
5. Transport systems	0.917	0.868	0.663	0.886	0.000	**0.667**	0.435	0.411	0.561	0.709	0.553	**0.534**
6. Energy efficiency and energy saving	0.592	0.741	0.829	0.765	0.000	**0.585**	0.341	0.495	0.696	0.838	0.514	**0.577**
7. Nuclear energy	0.742	0.781	0.779	0.584	0.369	**0.651**	0.293	0.833	0.504	0.615	0.300	**0.509**
8. Renewable energy resources	0.762	0.646	0.681	0.546	0.607	**0.649**	0.485	0.450	0.668	0.693	0.551	**0.569**
9. Search, explor., dev. and mining of minerals	0.854	0.896	0.639	1.000	0.771	**0.832**	0.406	0.717	0.387	0.667	0.580	**0.551**
10. Climate change, envir. Protect. and disaster manag.	0.424	0.535	0.454	0.539	0.556	**0.502**	0.470	0.542	0.505	0.610	0.620	**0.549**
11. Water resources	0.854	0.857	0.643	0.767	…	**0.780**	0.621	0.487	0.604	0.655	0.687	**0.611**
12. Food security and sustainable agriculture	0.600	0.742	0.745	0.975	0.692	**0.751**	0.660	0.387	0.526	0.667	0.518	**0.552**
13. Healthcare and medicine	0.867	0.780	0.677	0.624	0.633	**0.716**	0.488	0.469	0.667	0.720	0.561	**0.581**
14. Biotechnology	0.688	0.793	0.675	0.806	0.788	**0.750**	0.511	0.403	0.664	0.712	0.636	**0.585**
Average level (among 14 priority areas)	**0.716**	**0.778**	**0.698**	**0.746**	**0.590**	…	**0.441**	**0.529**	**0.587**	**0.701**	**0.523**	…

Fig. 4. Values of National R&D Capacity Index and National Index of Importance for 14 priority areas for BRICS countries.
Source: Authors' calculations.

Fig. 7 shows the profile of Russia in comparison with other BRICS countries.

The analysis shows that for most of the thematic fields Russia lags behind other BRICS countries on R&D capacity. For 59 (out of 74) thematic fields the value of Russia's R&D Capacity Index vs. other BRICS countries is below 0.50; for 37 – below 0.25.

The value of Russia's R&D Capacity Index vs. other BRICS countries is higher than 0.75 in eight thematic fields: "Technologies for reducing possible negative effects of space activities and threats to the safety of life on Earth from celestial bodies" (0.755); "Technologies and control systems for space vehicles and systems" (0.817); "Technologies of advanced nuclear reactors" (0.827); "Technologies for the development and extraction of mineral resources in areas characterized by extreme natural and climatic conditions (the Arctic shelf, the World Ocean, etc.)" (0.864); "Spent nuclear waste storage and utilization technologies (0.952); "Technologies for ensuring the integrated safety of operations on the continental shelf of the Russian Federation, the Arctic, and Antarctic" (0.989); "Technologies for closing the nuclear fuel cycle for fast neutron reactors" (0.998); and "Technologies for small and medium power reactors" (1.0).

Table 2 provides an assessment of Russia's R&D capacity vs. other BRICS countries for 14 priority areas.

Russia has comparatively high R&D capacity in "Space systems and astronomical observations"; "Nuclear energy"; "Search, exploration, development and mining of minerals" and to a lesser extent in "Climate change, environmental protection and disaster management". In some priority areas, Russia and other BRICS countries have comparable R&D capacity level: "Nanotechnology and new materials", "Energy efficiency and energy saving"; and "Water resources". In other priority areas, Russia lags behind the leading BRICS countries. In these priority areas (primarily in "Biotechnology"), Russia might be interested in intensifying collaboration with BRICS countries to gain knowledge and benefit from technology transfer. Similar calculations can be done for any other BRICS country. An analysis of the resulting profiles of all BRICS countries allows one to select pairs of BRICS countries that may be interested in various forms of cooperation in different thematic fields.

For the areas where Russia's research capacity lags behind other BRICS countries, possible modes of collaboration include the attraction of researchers from BRICS to work in Russia or the mobility of Russian researchers in BRICS countries. In areas where Russia and BRICS countries have comparable R&D capacities, they can jointly fund research projects and programs. In the areas with strong national R&D capacity, policymakers could encourage the participation of Russian researchers in research projects implemented in other BRICS countries as well as the mobility of researchers from BRICS countries to Russian research organizations.

Priority Areas	Share of respondents who selected this variant of the answer					NII value (BRICS Average)
	Very low	Low	Medium	High	Very High	
1. Information and communication technologies	3.2%	4.3%	10.7%	37.2%	44.5%	0.830
2. Nanotechnology and new materials	1.2%	4.6%	16.3%	29.2%	48.7%	0.765
3. Advanced manufacturing and robotics	4.6%	9.2%	16.4%	26.4%	43.4%	0.732
4. Space systems and astronomical observations	6.9%	5.6%	10.9%	28.9%	47.7%	0.705
5. Transport systems	0.4%	3.0%	13.4%	28.1%	55.2%	0.667
6. Energy efficiency and energy saving	5.4%	2.9%	21.9%	29.9%	39.9%	0.585
7. Nuclear energy	10.1%	5.8%	15.8%	25.4%	42.9%	0.651
8. Renewable energy resources	3.2%	17.8%	28.4%	25.1%	25.4%	0.649
9. Search, exploration, development and mining of minerals	3.6%	9.7%	14.3%	21.4%	51.0%	0.832
10. Climate change, environmental protection and disaster management	11.1%	22.1%	26.2%	38.9%	1.6%	0.502
11. Water resources	1.9%	8.6%	16.8%	29.5%	43.2%	0.780
12. Food security and sustainable agriculture	0.7%	7.6%	20.1%	36.0%	35.5%	0.751
13. Healthcare and medicine	5.7%	6.5%	18.8%	32.7%	36.3%	0.716
14. Biotechnology	2.5%	6.9%	19.4%	32.8%	38.4%	0.750

Fig. 5. The distribution of answers by respondents from BRICS countries: "Estimate the importance of thematic fields of the selected priority area for your country".
Note. Sum of shares of responses by for five variants of answers for a specific priority area is 100%.
Source: Results of expert survey and authors' calculations.

Priority areas	Russia			
	Share of respondents who selected this variant of the answer			NDRCI Value
	At leading edge	Average Performer	Lagging Behind	
1. Information and communication technologies	24.7%	52.6%	22.7%	0.491
2. Nanotechnology and new materials	14.1%	40.9%	45.1%	0.559
3. Advanced manufacturing and robotics	13.9%	42.2%	43.9%	0.455
4. Space systems and astronomical observations	23.3%	39.5%	37.2%	0.703
5. Transport systems	10.2%	35.8%	54.0%	0.411
6. Energy efficiency and energy saving	4.2%	48.2%	47.6%	0.495
7. Nuclear energy	71.2%	18.0%	10.9%	0.833
8. Renewable energy resources	10.4%	26.0%	63.6%	0.450
9. Search, exploration, development and mining of minerals	19.8%	31.0%	49.2%	0.717
10. Climate change, environmental protection and disaster management	15.7%	36.1%	48.2%	0.542
11. Water resources	10.4%	24.0%	65.6%	0.487
12. Food security and sustainable agriculture	2.6%	31.8%	65.6%	0.387
13. Healthcare and medicine	4.9%	33.2%	61.9%	0.469
14. Biotechnology	7.3%	35.8%	56.8%	0.403

Fig. 6. The distribution of answers by Russian respondents: "Estimate S&T capability of your country vis-a-vis leading countries in thematic fields of the selected priority area".
Note. Sum of shares of responses by three variants of answer for a specific priority area is 100%.
Source: Results of expert survey and authors' calculations.

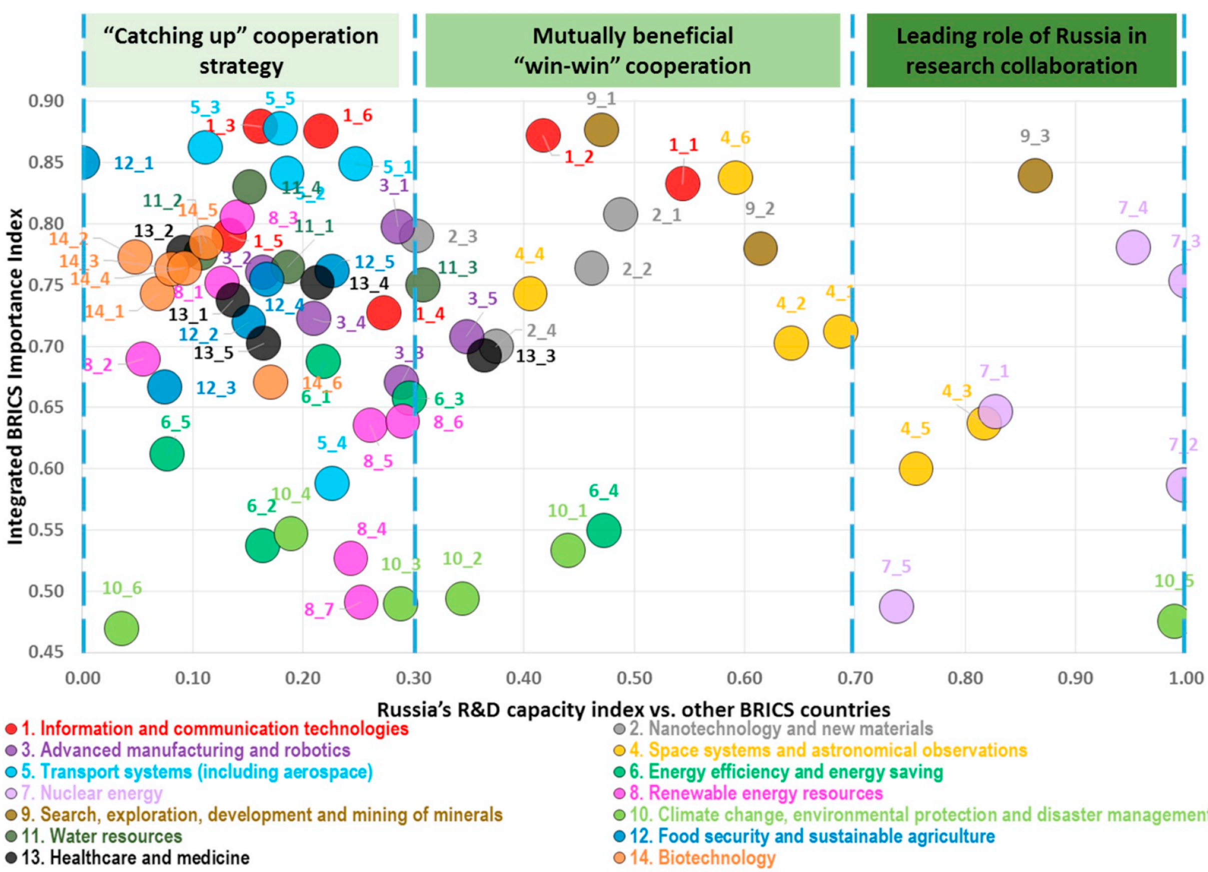

Fig. 7. Profile of Russia's R&D capacity vs. other BRICS countries in the context of thematic fields.

4.4. Key instruments to support research collaboration

The aforementioned priority areas were included in an expert survey as the basis for suggesting relevant implementation mechanisms, including both opportunities for cooperation between Russia and BRICS countries, possible thematic fields for joint projects, and relevant potential partners from BRICS countries (specific companies, R&D centers, universities, etc.).

The best suited (from the experts' point of view) international collaboration instrument and mechanisms were suggested for each priority area (see Fig. 8).

The most important collaboration mechanism, according to the experts, is joint R&D projects. It was selected by 82% of respondents from BRICS. Another important instrument for research collaboration is

Table 2
Assessment of Russia's R&D capacity vs. other BRICS countries for 14 priority areas.

Priority areas	National R&D Capacity Index value					National R&D Capacity Index of Russia minus National R&D Capacity Index of BRICS country				Schematic scores of Russia's R&D Capacity Index vs. other BRICS			
	BRA	**RUS**	IND	CHI	SAR	BRA	IND	CHI	SAR	BRA	IND	CHI	SAR
1. Information and communication technologies	0.442	**0.491**	0.651	0.729	0.442	−0.050	0.159	0.237	−0.049	↔	↓	↓	↔
2. Nanotechnology and new materials	0.343	**0.559**	0.644	0.748	0.434	−0.216	0.086	0.189	−0.125	↑	↔	↓	↑
3. Advanced manufacturing and robotics	0.359	**0.455**	0.587	0.823	0.446	−0.096	0.133	0.369	−0.008	↔	↓	↓	↔
4. Space systems and astronomical observations	0.320	**0.703**	0.550	0.635	0.478	−0.383	−0.153	−0.068	−0.225	↑↑	↑	↔	↑
5. Transport systems	0.435	**0.411**	0.561	0.709	0.553	0.024	0.150	0.298	0.142	↔	↓	↓	↓
6. Energy efficiency and energy saving	0.382	**0.523**	0.717	0.798	0.593	−0.140	0.195	0.316	0.070	↑	↓	↓	↔
7. Nuclear energy	0.293	**0.833**	0.504	0.615	0.300	−0.541	−0.329	−0.219	−0.534	↑↑	↑↑	↑	↑↑
8. Renewable energy resources	0.485	**0.450**	0.668	0.693	0.551	0.035	0.218	0.243	0.101	↔	↓	↓	↓
9. Search, exploration, development and mining of minerals	0.406	**0.717**	0.387	0.667	0.580	−0.311	−0.330	−0.050	−0.137	↑↑	↑↑	↔	↑
10. Climate change, environmental protection and disaster management	0.470	**0.550**	0.451	0.563	0.538	−0.071	−0.037	0.068	0.078	↔	↔	↔	↔
11. Water resources	0.565	**0.513**	0.547	0.600	0.683	0.052	0.035	0.087	0.170	↔	↔	↔	↓
12. Food security and sustainable agriculture	0.660	**0.387**	0.526	0.667	0.518	0.273	0.139	0.280	0.131	↓	↓	↓	↓
13. Healthcare and medicine	0.488	**0.469**	0.667	0.720	0.561	0.019	0.197	0.251	0.091	↔	↓	↓	↔
14. Biotechnology	0.511	**0.403**	0.664	0.712	0.636	0.108	0.261	0.309	0.233	↓	↓	↓	↓

Note. The schematic scores of Russia's R&D Capacity Index vs. other BRICS are estimated as follows: ↑ and ↑↑ – BRICS country lags behind Russia in the development of the priority area: Russia can play a leading role in research collaboration; ↔ – Russia and the other BRICS country have comparable levels of R&D capacity: mutually beneficial “win-win” cooperation; ↓ – Russia lags behind BRICS countries in the development of the priority area: “catching up” cooperation strategy.
Source: Authors' calculations.

Priority area	Share of respondents who selected this variant of the answer								
	Joint R&D projects	Researcher mobility (incoming and outgoing)	Information exchange, shared access to databases, scientific collections, archives, and	Establishing joint research centers (e.g., Joint Institute for Nuclear Research)	Joint innovation and S&T entrepreneurship projects	Joint industrial research projects with high potential for commercialization	Creating international advanced research centers (incl. virtual) in priority research areas	Joint participation in large research infrastructures (like Large Hadron Collider)	Other (please specify)
1. Information and communication technologies	88.6%	40.0%	12.9%	20.0%	18.6%	27.1%	21.4%	32.9%	2.9%
2. Nanotechnology and new materials	85.1%	50.4%	20.9%	26.1%	22.4%	24.3%	16.4%	19.0%	1.5%
3. Advanced manufacturing and robotics	75.0%	41.7%	29.2%	29.2%	41.7%	37.5%	25.0%	16.7%	…
4. Space systems and astronomical observations	77.1%	44.3%	31.4%	30.0%	12.9%	7.1%	24.3%	34.3%	…
5. Transport systems (including aerospace)	69.0%	37.9%	37.9%	13.8%	27.6%	37.9%	27.6%	…	…
6. Energy efficiency and energy saving	82.8%	41.4%	20.7%	27.6%	37.9%	34.5%	17.2%	6.9%	…
7. Nuclear energy	69.2%	46.2%	23.1%	53.8%	19.2%	11.5%	11.5%	42.3%	3.8%
8. Renewable energy resources	76.2%	47.6%	23.8%	21.4%	21.4%	40.5%	21.4%	19.0%	…
9. Search, exploration, development and mining of minerals	91.4%	28.6%	34.3%	25.7%	8.6%	34.3%	20.0%	14.3%	…
10. Climate change, environmental protection and disaster management	80.0%	41.3%	45.3%	17.3%	26.7%	14.7%	24.0%	18.7%	…
11. Water resources	86.4%	50.0%	45.5%	27.3%	36.4%	13.6%	18.2%	4.5%	…
12. Food security and sustainable agriculture	78.8%	66.7%	24.2%	21.2%	51.5%	6.1%	12.1%	12.1%	…
13. Healthcare and medicine	81.2%	50.6%	30.6%	27.1%	17.6%	18.8%	29.4%	12.9%	1.2%
14. Biotechnology	82.6%	44.9%	31.9%	21.7%	23.2%	24.6%	14.5%	13.0%	1.4%
Total (all priority areas)	**82.0%**	**46.4%**	**27.3%**	**25.1%**	**23.3%**	**22.8%**	**20.0%**	**19.0%**	**1.0%**

Fig. 8. The distribution of answers by respondents from all BRICS Countriesto the question: “Select the most promising (no more than 3) instruments of international collaboration for the support of the selected priority area”
Note. The sum of the shares of responses for the nine variants of answer for a specific priority area exceeds 100% since respondents can select up to three instruments for international collaboration.
Source: Results of the expert survey and authors' calculations.

the incoming and outgoing mobility of R&D personnel (46.4% of answers of respondents from BRICS countries on average among 14 priority areas). There are some differences in the “profiles” of instruments of support for research collaboration across the studied priority areas. For “Nuclear energy” among the most important instruments were “Establishing joint research centers (e.g., Joint Institute

Priority Areas	Share of respondents who selected this variant of the answer				
	Brazil	Russia	India	China	SAR
1. Information and communication technologies	19.0%	41.6%	49.1%	67.9%	3.2%
2. Nanotechnology and new materials	14.4%	40.2%	52.1%	70.7%	10.4%
3. Advanced manufacturing and robotics	24.0%	45.3%	29.1%	81.3%	9.5%
4. Space systems and astronomical observations	15.6%	49.9%	42.9%	67.4%	13.8%
5. Transport systems	11.6%	28.2%	43.0%	87.0%	5.1%
6. Energy efficiency and energy saving	12.7%	40.9%	50.4%	66.4%	12.1%
7. Nuclear energy	11.6%	57.1%	38.8%	58.8%	13.9%
8. Renewable energy resources	23.9%	34.3%	49.5%	60.1%	12.9%
9. Search, exploration, development and mining of minerals	22.5%	55.0%	26.8%	62.4%	20.0%
10. Climate change, environmental protection and disaster management	16.1%	20.7%	25.0%	40.1%	9.3%
11. Water resources	54.0%	24.8%	49.2%	50.1%	16.8%
12. Food security and sustainable agriculture	41.0%	19.9%	41.8%	61.6%	20.2%
13. Healthcare and medicine	15.0%	33.2%	36.7%	55.0%	2.8%
14. Biotechnology	20.5%	34.8%	45.8%	72.9%	9.6%

Fig. 9. The distribution of answers by respondents from all BRICS countries to the question: "For the thematic fields of the selected priority area please select no more than two BRICS countries that are most promising for scientific collaboration"
Note. The sum of the shares of responses with five variants of the answer for a specific priority area exceeds 100% since respondents can select up to two countries.
Source: The results of expert survey and authors' calculations.

for Nuclear Research)" and "Joint participation in large research infrastructure (like the Large Hadron Collider)". Joint participation in large research infrastructure was also selected as an important tool for collaboration for "Information and communication technologies" and "Space systems and astronomical observations". The instrument "Joint innovation and S&T entrepreneurship projects" was of highest importance for "Advanced manufacturing and Robotics" and "Food security and sustainable agriculture"; while the instrument "Information exchange, shared access to databases, scientific collections, archives, and libraries" received the greatest amount of attention for "Climate change, environment protection and disaster management" and "Water resources".

The evaluation of the collaboration potential of BRICS countries is provided in Fig. 9, which summarizes the responses to the question related to most promising BRICS countries for scientific collaboration. It was used to calculate the Collaboration Potential Index, a component of National R&D Capacity Index.

The analysis of the data allows one to not only assess the overall collaboration potential of different nations in the alliance (China and to a lesser extent India have high level of in many priority areas, while South Africa lags behind other BRICS countries in this respect) but also to identify particular research fields and relevant collaboration instruments for establishing mutually beneficial cooperation with any country in the alliance. Among such areas are, for example, "Advanced manufacturing and robotics" and "Transport systems" for China, "Water resources" and "Food security and sustainable agriculture" for Brazil, "Search exploration, development and mining of resources" and "Food security and sustainable agriculture" for South Africa.

5. Conclusions

International STI cooperation has become one of the most important policy instruments in many countries, particularly for BRICS members. First, such cooperation can address global issues and search for efficient responses to grand challenges. It allows for concentrating joint efforts on urgent problems like climate change, environment, migration, infectious diseases, hunger, and so on. All this also contributes to increasing the quality of research and provides better visibility for both individual researchers and relevant countries.

If organized in line with win-win principles, STI cooperation can bring significant benefits to all participants. Countries that are catching can gain access to new knowledge, develop their human resources, and increase research capacity and performance. More developed countries can instil "new blood" in their research centers and universities by engaging talented young researchers from abroad and thus expand their influence on new markets. Beside these, partner countries can identify research areas of particular importance for all of them and support joint activities using a wide range of tools: joint funding of international S&T programs, building research infrastructure, and promoting research mobility.

The selection of STI priorities for international collaboration is a very important and rather complicated process. So far, it has been mostly implemented on the basis of consultations within joint committees of different kinds and/or through expert-based studies and Foresight-like exercises. This process as a rule involves the application of qualitative methods and more rarely quantitative ones. At the same time, the rapid growth of modern IT-based techniques opens doors for applying new methods, for example, those based on the intellectual analysis of big data, bibliometric and patent analysis, which provide policy-makers a background for the sounder selection of priorities for STI collaboration.

The approach presented in the paper demonstrates how a set of quantitative methods can be applied for the identification of STI priorities for cooperation in a group of countries like BRICS members.

Given the tougher government budget limitations and the need to use resources more efficiently, this study aimed at selecting a list of priorities for international STI cooperation between BRICS members. Priority setting combined traditional research involving major STI-related policy documents complemented by interviews with leading experts from all member countries. This allowed us to identify a two-level system of 14 priority areas and 74 more focused thematic fields that can contribute to the socioeconomic development of all BRICS countries. An important criterion for the selection of priorities was their ability to find common responses to global challenges. Altogether the selected priorities should correspond with national strategies and programs for STI development. The developed system of common STI priorities for BRICS members includes major directions of global STI development, thus reflecting the compliance of research agenda of BRICS countries with research forefronts. Moreover, these priorities are aimed at the solution of specific problems that are most relevant for BRICS members, like water resources and their use; climate change, environmental protection and disaster management; and the exploration and extraction of minerals.

For the complex assessment of the system of common STI priorities of BRICS countries, this paper provides a set of composite indices reflecting the importance of the selected priorities (National Index of

Importance) and R&D capacity level of BRICS countries (National R&D Capacity Index). The primary information needed to calculate these indices was collected through a specially organized expert survey and on the basis of big data analysis and bibliometric and patent analysis. The involvement of quantitative techniques demonstrates how qualitative expert estimates can be supported (and in some cases corrected) by a thorough analysis of the strength and weaknesses of individual countries both in broader and rather narrow research areas (e.g. via bibliometric and patent analysis). Based on the analysis of the proposed composite indices, three types of priorities for STI cooperation have been identified, depending on the potential interest of BRICS members in collaborating with each other, and suggested STI policy tools for such cooperation. Use of the aforementioned indices of importance and R&D capacity complemented with bibliometric and patent analysis can help one cluster research areas by a comparative analysis of strengths and weaknesses of potential partner countries and, on this basis, select the most relevant strategies and tools of STI cooperation in different research areas.

Thus, this paper proposes an approach for the use of quantitative methods to better focus international STI collaboration policy. The list of STI cooperation priorities for BRICS countries can be used to design intergovernmental agreements between BRICS and other countries, R&D plans (roadmaps), and other policy tools. In particular, it was used for the identification of research topics to be funded by calls within the BRICS STI Framework Program. The selected priorities form the basis for joint research projects and exploratory projects for innovative technologies, STI entrepreneurship development, and the commercialization of R&D results. International cooperation will be more effective if it includes all the stages of the innovation cycle – from obtaining new fundamental knowledge to their use in the creation of new technologies, products, and services and their entry onto the market. All this helps individual countries gain benefits from STI cooperation in the framework of bilateral and multilateral cooperation within the already set up system of STI priorities.

One of the possible ways forward for the further development of research is organization-level analysis. In this case, the selection of priorities can be complemented by a detailed analysis of the STI capacities of research organizations of partner countries. Based on this analysis, possible participants in the prospective mutually beneficial international STI areas can be identified. Subsequently, the project results can be applied to build an information base to be used by various participants of the national innovation system, help them formulate topics for STI cooperation, find partners including research organizations, universities, and enterprises, and identify the most effective instruments for promoting research cooperation.

The proposed approach can be further improved by fine-tuning the relevant composite indices taking account of the peculiarities of partner countries. One of the important research questions concerns which components and information bases should be used for the calculation of the indices. The set of composite indices presented in the paper is based on conventional indicators (like levels of citation, indices of S&T specialization, and the quantified results of an expert survey). The modification of the proposed set of composite indices could cover more sophisticated bibliometric and patent indicators as well as surveys aimed at particular aspects of STI collaboration policy.

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Appendix A

Table A.1
Key S&T foresight projects in BRICS.

Country, project, organizer	Goals	Time horizon	Methods	Results
Brazil. Brazil 3 Moments Project, (Administration of the President)	National strategic objective identification	2022	Trend analysis, expert discussion, Delphi survey, scenarios	Three scenarios for the country's future until 2007, 2015, 2022; 50 STI priorities
Russia. Priority Areas and Critical Technologies, (Ministry of Education and Science)	R&D areas with high commercial potential and significant socioeconomic impact	2020	Expert interview and surveys, expert panels, critical technologies	Nine Priorities Areas and 27 Critical technologies
Russia. Science and Technology Foresight 2030, (-Ministry of Education and Science)	The identification of S&T areas for the implementation of a country's competitive advantages	2030	Grand challenges, bibliometric and patent analysis, expert panels, expert survey, roadmaps	Six priority S&T areas, 50 thematic areas, more than 1000 detailed S&T goals
India. Technology Vision 2020, 2035 (Technology Information, Forecasting & Assessment Council, Department of Science & Technology)	An assessment of key technology areas and their socioeconomic implications	2020,	Expert interviews, expert panels, Delphi survey, critical technologies, technology roadmap	More than 10 priorities areas and key technology areas, around 100 sub-sectors; 12 Technology roadmaps
China. Technology Foresight 2020 (Chinese Academy of Sciences)	S&T landscape evaluation and critical technologies selection	2020	Expert panels, Delphi survey, critical technologies, scenario analysis, technology roadmaps	Eight fields, 62 sub-fields and 737 technology topics
China. Science & Technology in China: A Roadmap to 2050 (Chinese Academy of Sciences)	Investment planning for the STI development of industries	2050	Expert panels, Delphi sur-vey, critical technologies, scenario analysis, technology roadmaps	Eighteen technology roadmaps for different fields and sectors
South Africa. National Research and Technology Foresight (Department of Arts, Culture, Science and Technology)	The identification of promising areas for R&D funding	2020	Expert interview and surveys	List of the most important technologies

*Prepared by the authors on the basis of the following sources Mojica, 2010; Santos, 2006; Shashnov and Poznyak, 2011; Sokolov and Chulok, 2016; Chan and Daim, 2012; TIFAC, 2015; Rongping et al., 2008; Yongxiang, 2010; Pouris and Raphasha, 2015.

Table A.2
Examples of the extraction of STI areas from strategic, foresight, and STI policy documents in BRICS countries.

Document title (country; time horizon)	S&T development thematic areas derived from the text	Priority areas attached to S&T areas derived from the text
Science, Technology and Innovation Policy 2013 (India, 2013–2020)	Agriculture, telecommunications technology; Energy; Water management; Healthcare and drug development; Mining of materials, Environment protection and climate change, Space research and technology	AGRIC; ICT; ENER EFF; WATER; HEALTH; NANO; ENVIR; SPACE
National Medium and Long-term Plan for the Development of Science and Technology (2006–2020) (China; 2006–2020)	Biotechnology; Information and telecommunication technologies; New materials; Advanced engineering and industrial equipment; Energy; Marine technology; Laser technology; Ecology; Transport; Healthcare; Aerospace technology; Water and mineral resources; Agriculture; Public health, Urbanization, Public and national security	BIOTECH; ICT; NANO; ADV MANUF; ENVIR; HEALTH; SPACE; WATER; FOOD
National Strategy for Science, Technology, and Innovation 2016–2019 (Brazil; 2016–2019)	Aerospace and defense industry; Water resources; Food supply; Bioeconomy and biomes; Social technologies; Climate, economy and digital society; Energy, Nuclear energy; Medicine; Convergent and supporting technologies	TRANSP; WATER; AGRIC; BIOTECH; ICT; ENER EFF; NUCL ENER; HEALTH
South Africa's National Research and Development Strategy (South Africa; since 2002)	Water supply and sewage; Food security and agriculture; Education; Healthcare; Energy; Information and communication technologies; Mineral resources mining; Advanced production technologies	WATER; FOOD; HEALTHCARE;
Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030 (India; 2016–2030)	Recycling; Use of recycled materials after the primary processing process; Minimum impact of mining industry on the environment	ENVIR
Vision for 2030 (India; 2016–2030)	Weather, climate and hydrological services; Marine geology; Ocean sciences; Atmospheric and marine technology; Geosciences and seismology	MINING; ENVIR; WATER
National Development Plan 2030: Our future - make it work (South Africa; 2012–2030)	Climate change; Education and training: Energy; Water supply; Agriculture; Healthcare	ENVIR;
Science and Technology Innovation 2030: Megaprojects (China, 2016–2030)	Aircraft engines; Quantum communications; Cyberspace; Intelligent manufacturing and robotics; Monitoring of deep space and deep ocean: New materials; Brain science; Healthcare; Seed production among others	ADV MANUF; NANO; HEALTH

Note. Fourteen priority areas are abbreviated as follows: 1. Information and communication technologies (ICT); 2. Nanotechnology and new materials (NANO); 3. Advanced manufacturing and robotics (ADV MANUF); 4. Space systems and astronomical observations (SPACE); 5. Transport systems (including aerospace) (TRANSP); 6. Energy efficiency and energy saving (ENER EFF); 7. Nuclear energy (NUCL ENER); 8. Renewable energy resources (RENEW ENER); 9. Search, exploration, development and mining of minerals (MINING); 10. Climate change, environmental protection and disaster management (ENVIR); 11. Water resources (WATER); 12. Food security and sustainable agriculture (FOOD); 13. Healthcare and medicine (HEALTH); 14. Biotechnology (BIOTECH).

Table A.3
Synthesis of STI areas extracted from the Corpus of strategic, foresight, and STI policy documents and BRICS member States' national STI development and cooperation priorities.

Board thematic area	Brazil	Russia	India	China	South Africa	International documents
Information and telecommunication systems	Economics and digital society; **Information and communication technologies**; Cybersecurity	**Information and communication technology**; Big Data systems, machine learning, artificial intelligence; Quantum communications; Control and management systems	**Information and communication technologies**; Telecommunication technologies	**Information technologies**; Cyberspace, including cybersecurity; Advanced electronics; Telecommunications	**Information and communication technology**; Digital economy	**Information and communication technology**; High-performance computing; Photonics
Life sciences	**Health**; Pharmaceutics; Biomes and bioeconomics; **Biotechnology**	Personalized medicine, high-tech healthcare, health-improving technologies; Medicine and health; Genomics and synthetic biology; Neurotechnology; **Biotechnology**	**Health**; Pharmaceutics; Medical equipment; **Biotechnology**	**Health**, **healthcare**; **Medicine**; Neuroscience; Pharmaceutics, biopharmaceutics; **Biotechnology**	**Health**; **Biotechnology**; Pharmaceutics; Bioeconomy	**Medicine and biotechnology**; Biomedicine and life sciences (biomedical engineering, bioinformatics, biomaterials); **Biotechnology and biomedicine, including healthcare and neuroscience**
Agriculture	**Food supply**; Agriculture; Biodiversity; **Biotechnology**	Highly productive green agriculture and aquaculture; Efficient chemical and biological crops and farm animal protection systems; Efficient storage and processing of agricultural products; **Production of safe, high-quality foods**; **Biotechnology**; Personal food and water production and delivery systems	**Sustainable agriculture**; Animal farming; **Biotechnology**	Agriculture; **Agrifood products**; **Food industry**; **Biotechnology**	Agriculture; Fisheries; **Food supply**; Biodiversity; Biotechnology	**Food security and sustainable agriculture**; **Biotechnology**

(continued on next page)

Table A.3 (*continued*)

Board thematic area	Brazil	Russia	India	China	South Africa	International documents
New materials, nanotechnology	**Nanotechnology**	New materials and design techniques; **New materials and nanotechnology**	**Materials**	**New materials**; **Nanotechnology**	**Nanosystems and materials**; **Nanotechnology**	**Nanotechnology**; **Materials science**
Efficient environment management	**Environment protection**; **Climate change**; **Water resources**; Ocean, and coastal areas; **Hydrocarbon production**; Green economy; Preserving biodiversity	**Efficient environment management**; More efficient production and deep processing of hydrocarbons; **Reducing risks, and managing consequences of natural and anthropogenic disasters**; Countering anthropogenic and biogenic threats	**Climate change**; Predicting climate change impact; **Environment protection**; **Water resources**; Marine studies; Geosciences, seismology; Himalayan ecosystem; Green technologies; **Non-fuel mineral resources**; Waste management	**Water and mineral resources**; **Ecology**; **Environment**; Deep prospecting and drilling; Deep-water exploration; **Water resources**; Mineral production; Oceanography; Marine technologies	**Climate change**; **Production of mineral resources**; Green economy; **Water resources**; **Environment**; Waste recycling	**Water resources**, managing water pollution; marine and polar areas studies; Geospatial technologies and their application; **Prevention and management of natural disasters**; Marine and polar studies, and relevant technologies; Geospatial technology and its application
Energy	**Energy**; **Nuclear energy**; **Renewable energy sources**; Biofuel	Environmentally safe, resource-saving energy generation; new energy sources; new energy transmission and storage technologies; **Energy efficiency and energy saving**; **Nuclear and thermonuclear energy**; New energy sources	Energy; **Energy efficiency**; **Nuclear energy**; Solar energy; **Renewable energy sources**	Energy; Hydroenergy; **Energy saving**; **Next-generation nuclear energy, renewable and non-renewable energy sources**	Energy	**New and renewable energy sources**; **Energy efficiency**; Clean coal technologies; Natural gas and unconventional gas sources
Transport and space systems	**Aerospace technologies**; **Space**; **Transport, including high-speed systems**	Smart transport and telecommunication systems; transportation and logistics systems; Development of airspace and outer space, oceans, Arctic, and Antarctic areas; **Transport and space systems**; Distributed unmanned aerial vehicles systems; Unmanned transportation systems	**Space exploration and technologies**; **Urban transport**	**Space exploration**; **Aerospace equipment**; **Space technologies**; Navigation; **Transport**; High-speed railways; Automobile industry; Aircraft engine production; High-tech vessels; Railway equipment	**Aerospace technologies**; **Astronomy**	**Space exploration and development, aviation sciences**; **Astronomy**; Earth observation; Geospatial technology and its application
Production	Industry	**Advanced digital and smart production technologies**; Additive technologies; Smart technologies for robotic and mechatronic systems; Instruments and devices based on nano- and microsystem technologies; Sensory systems; Bionics	Industrial production; **Manufacturing**	**Advanced production technologies**; Smart production systems; Robotics; Additive production systems	**Advanced production technologies**	…
Security	Cybersecurity	Countering anthropogenic, biogenic, sociocultural threats, and cyber threats	…	Cyberspace, including cybersecurity	Information security	…

Note. BRICS countries' national S&T and innovation development priorities and priority cooperation areas that correspond to 14 priority areas are highlighted in bold.
Source: Derived from Sokolov et al. (2017). Lists of BRICS countries' national STI development priorities and priority cooperation areas were prepared by authors on the basis of an analysis of the corpus of nearly 150 strategic, Foresight, and STI policy documents.

Box A.1
Bibliometric and patent analysis.

Bibliometric and patent analysis was performed to estimate the level of S&T specialization of BRICS countries and the level of citation of publications in 74 thematic fields within 14 priority areas. Bibliometric analysis was based on the analysis of publications that are indexed in Web of Science database. Indicators derived from Web of Science for the period of 2012–2016 were used in the bibliometric analysis:

- Relative Comparative Advantages Index (RCA) (index of scientific specialization) of the country for a specific thematic field;
- Category Normalized Citation Impact (CNCI) of publications of BRICS country in a specific thematic field.

Patent activity indicators were derived from the Orbit database for the period of 2005–2015. Patent analysis was based on data on the registration of patent applications by researchers from BRICS member in technology domains and technology groups related to the studied thematic fields in national and international patent offices. In the analysis, the Relative Technological Advantages Index (RTA) (Index of technological specialization) of the country in a specific thematic field was used.

RCA, CNCI, and RTA indicators were used as integral parts of the **National R&D Capacity Index**.

Box A.2
Big data analysis.

Big data analysis was done using an intelligent Foresight analytics system called iFORA – a proprietary software of National Research University Higher School of Economics (examples of the applications of iFORA can be found in Kuzminov et al., 2018; Bakhtin et al., 2017). Using the algorithms of natural language processing and semantic analysis, the texts of 20 million news articles that are indexed in databases of media sources covering more than 2700 sources (like article feeds, news feeds, trade journals, popular journals, newspapers, magazines, news aggregators, blogs, press releases of companies and government organizations) and texts of more than 70 English-language strategic, Foresight, and STI policy documents of BRICS members were processed and keywords related to priority and thematic fields were searched.

To run the procedure of the semantic processing of news article and strategic STI policy documents for each of 74 thematic fields, a list of keywords (from eight to 47 keywords per thematic field) was developed that in best described and characterized a specific thematic field.[4] For all thematic areas, keywords were selected and further validated on the basis of consultations with key experts in the relevant fields. All words and word combinations for each specific thematic field were searched in all word forms.[5] All keywords (including all word forms that were detected via lemmatization) related to each specific thematic field in a query search were merged via an OR operator.

Mentions of keywords in a specific news article or STI policy document were counted at the level of sentences of the semantically processed item (news article or English language strategic, Foresight, and STI policy document) as follows. For a specific semantically processed item as a single mention of thematic field j, a single sentence of this item where at least one keyword of thematic field j is mentioned was counted. For example, if in a specific semantically processed item one keyword related with thematic field j is mentioned – this mention is counted as one mention of thematic field j. If in a specific semantically processed item in one sentence three keywords related with thematic areas j are mentioned while in the other sentence two other keywords related with thematic field j are mentioned, these mentions are counted as two mentions of thematic field j.[6]

Since data on the mentioning of keywords are presented in absolute values while values of all composite indices vary from 0.00 to 1.00, the normalized mentions of keywords have been calculated, which also vary from 0.00 to 1.00:

- for the thematic field with the minimal (among all 74 thematic fields) number of mentions, the value of normalized measure is set at 0.00;
- for the thematic field with the maximum (among all 74 thematic fields) number of mentions, the value of normalized measure is set at 1.00.

Data on keyword mentions in the database of news articles and the corpus of strategic, Foresight, and STI policy documents was used for the calculation of the **Integrated BRICS Importance Index**.

[4] E.g. for the thematic field 1.1 “High-performance computing architectures and systems”, a set of the following list of 21 keywords was used: supercomputer; blockchain; parallel computing; metacomputing; alternative architecture; data center; system architecture; NoSQL; exascale; petascale; quantum computer; high performance calculating; high performance computing; cloud computing; cloud service; cloud infrastructure.

[5] To detect all forms of a specific keyword the process of lemmatization – automatic detection of lemma of this keyword – was run. Lemma is canonical, dictionary, citation form of the set of words. E.g. for the words “runs”, “runner”, “runners”, “running” the lemma is “run”.

[6] The number of mentions of the studied 74 thematic fields in news articles varies from 220 (thematic field 7.3. Technologies for small and medium power reactors) to 911,583 (thematic field “6.4. Technologies for creating new light sources and intelligent lighting systems”). Twenty-two out of 74 thematic fields received more than 100,000 mentions in news articles. The number of mentions of the studied 74 thematic fields in English language strategic, Foresight, and STI policy documents varies from zero (i.e. no mentions) for 10 thematic fields to 480 mentions (thematic field 10.1 “Climate change and extreme climatic events forecasting technologies”). Thirty-seven thematic fields out of 74 received less than 10 mentions in strategic, Foresight, and STI Policy documents. Only six thematic fields received more than 100 mentions in strategic, Foresight, and STI policy documents.

Box A.3
Expert survey "Identification of S&T Priorities for BRICS Countries".

The selection of experts for the survey was based on the Scopus scientific citation database. As a foundation for research, the corpus of publications by Russian authors in collaboration with authors from BRICS countries in 14 priority areas published in 2005–2017 was taken. Further, corresponding authors, their names and initials, and their e-mails have been automatically detected using the information from the bibliographical description of the formed corpus of publications. Among all corresponding authors derived, only those affiliated with BRICS countries were counted. Further from all received publications, the electronic addresses of the authors responsible for the correspondence (corresponding author) were automatically identified by Scopus, their surname and initials, as well as their affiliation. Further, these authors (corresponding authors) were selected separately by Russian authors (i.e. authors who were affiliated with organizations from Russia), as well as authors from other BRICS countries (authors affiliated with organizations from India, Brazil, China, and South Africa).

Using this algorithm, 12,613 experts (authors) for the survey were selected, including 1159 experts from Brazil; 4954 experts from Russia; 2093 experts from India; 3550 experts from China; and 857 experts from South Africa.

The survey questionnaire was disseminated among these experts. It was aimed at the assessment of two major issues:

- the importance of the selected thematic fields for accomplishing key national STI development objectives;
- the countries' R&D capacity compared to global leaders.

As a result, responses were received from 877 experts (respondents) from BRICS countries – 61 respondents from Brazil, 371 from Russia, 276 from India, 127 from China, and 42 from South Africa. The "Nanotechnology and new materials" priority area took the highest share in the assessment by respondents of priority areas (30.6% of respondents). This corresponds to the thematic structure of Russia-BRICS joint publications in Scopus (55.8% of papers were concentrated in "Physics and astronomy" for 2011–2015).

Survey results were used for the calculation of the **National Index of Importanc**e, **Integrated BRICS importance Index** and also as components of the National R&D Capacity index (**Research Leadership Index** and **Index of Collaboration Potential**).

Box A.4
Questionnaire form for the "Identification of S&T Priorities for BRICS Countries" survey.

Which BRICS country is your organization affiliated with:

- Brazil;
- Russia;
- India;
- China;
- South Africa;
- Other country.

Select the type of your research organization:

- Institutes of national academies of sciences;
- Research organizations not related to national academies of sciences;
- Universities and other higher educational institutions, research organizations at higher educational institutions;
- Design and engineering organizations;
- Research subdivisions of production organizations and firms;
- Experimental enterprises, technological organizations;
- Other (please specify).

Have you had any publications in collaboration with foreign researchers in the last 10 years:

- Yes, only with researchers from BRICS;
- Yes, with researchers from BRICS and other countries;
- Yes, with researchers from other countries, but not from BRICS;
- No, I haven't had any joint publications with foreign researchers in the last 10 years.

Choose one S&T priority area, **which most corresponds to the sphere of your interests***:

- Information and communication technologies;
- Nanotechnology and new materials;
- Advanced manufacturing and robotics;
- Space systems and astronomical observations;
- Transport systems (including aerospace);
- Energy efficiency and energy saving;
- Nuclear energy;
- Renewable energy resources;
- Search, exploration, development and mining of minerals;
- Climate change, environmental protection and disaster management;
- Water resources;
- Food security and sustainable agriculture;
- Healthcare and medicine;
- Biotechnology.

*After choosing one area, the respondent was redirected to questions (that are the same for all 14 priority areas) related to the selected priority area. Expert can select several priority areas. Further, the questions for the priority area “Information and communication technologies” are provided as example.

Please indicate the degree of your expertise in “Information and communication technologies” priority areaˆ

- I currently work in this priority area;
- I worked in this priority area previously;
- I current work in a related field of science;
- I follow the progress (or have general knowledge) in this field;
- Other (please specify).

Estimate the importance of the thematic fields of the “Information and communication technologies” priority area for your country.

Thematic fields	Very low	Low	Medium	High	Very high	Difficult to answer
High-performance computing architecture and systems						
High-speed data transmission technologies and communication infrastructures						
Artificial intelligence technologies, data analysis technologies, data processing technologies						
Human-machine interaction technologies, neurotechnologies, cognitive technologies						
Technologies for creation of intelligent control systems and smart infrastructure, machine-machine interaction technologies; Internet of Things						
New element base technologies, electronic devices, quantum technologies						
Information security technologies						

Evaluate the S&T capability of your country vis-a-vis leading countries in the thematic fields of the “Information and communication technologies” priority area.

Thematic fields	At leading edge	Average performer	Lagging behind	Difficult to answer
High-performance computing architecture and systems				
High-speed data transmission technologies and communication infrastructures				
Artificial intelligence technologies, data analysis technologies, data processing technologies				
Human-machine interaction technologies, neurotechnologies, cognitive technologies				
Technologies for creation of intelligent control systems and smart infrastructure, machine-machine interaction technologies; Internet of Things				
New element base technologies, electronic devices, quantum technologies				
Information security technologies				

Select the most promising (no more than three) instruments of international collaboration for the support of the “Information and communication technologies” priority area:

- Joint R&D projects;
- Joint innovation and S&T entrepreneurship projects;
- Joint industrial research projects with high potential for commercialization;
- Creating international advanced research centers (incl. virtual) in priority research areas;
- Establishing joint research centers (e.g., Joint Institute for Nuclear Research);
- Joint participation in large research infrastructure (like the Large Hadron Collider);
- Information exchange, shared access to databases, scientific collections, archives, and libraries;
- Researcher mobility (incoming and outgoing);
- Other (please specify).

For the thematic field “Technologies and communication infrastructures of high-speed data transmission” please select no more than two BRICS countries that are most promising for scientific collaboration.

Thematic fields	Brazil	Russia	India	China	South Africa	Difficult to answer
High-performance computing architecture and systems						
High-speed data transmission technologies and communication infrastructure						
Artificial intelligence technologies, data analysis technologies, data processing technologies						
Human-machine interaction technologies, neurotechnologies, cognitive technologies						
Technologies for creation of intelligent control systems and smart infrastructure, machine-machine interaction technologies; Internet of Things						
New element base technologies, electronic devices, quantum technologies						
Information security technologies						

Box A.5
Formulas used for the calculation of components for National R&D Capacity Index.

The formula for the calculation of the **National Index of Importance** (**NII**) for country thematic field j presented in Eq. (1):

$$NII_{ij} = (N\ resp_{very\ high\ ij} \times 1.00 + N\ resp_{high\ ij} \times 0.75 + N\ resp_{medium\ i} \times 0.50 + N\ resp_{low\ ij} \times 0.25 + N\ resp_{very\ low\ ij} \times 0.00) \div (N\ resp_{total\ ij} - N\ resp_{diff\ answ\ ij}) \quad (1)$$

$N\ resp_{very\ high\ ij}$ – number of respondents from country i who selected the "Very high" variant for thematic field j; $N\ resp_{high\ ij}$ – number of respondents from country i who selected the "High" variant for thematic field j; $N\ resp_{medium\ ij}$ – number of respondents from country i who selected the "Medium" variant for thematic field j; $N\ resp_{low\ ij}$ – number of respondents from country i who selected the "Low" variant for thematic field j; $N\ resp_{very\ low\ ij}$; – number of respondents from country i who selected the "Very Low" variant for thematic field j; $N\ resp_{total\ ij}$ – total number of respondents from country i who answered the question for thematic field j; $N\ resp_{diff\ answ\ ij}$ - number of respondents from country who selected the "Difficult to evaluate" option for thematic field j.

When quantifying the answers of the respondents, the "Very high" variant receives 1.00 points, "High" – 0.75, Medium – 0.50 points, Low – 0.25 points, and Very Low – 0.00 points. Further, these points were weighted along the distribution of respondent answers according to answer variants.

As a result, the NII value varies from 0.00 (minimum importance of a specific thematic field for a specific country) to 1.00 (maximum importance of a specific thematic field for a specific country).

This approach for the quantification of survey results – setting certain points (scores) for all answer variants for specific survey questions – is based on the survey question quantification methodology applied in the Global Competitiveness Reports (GCR) that are prepared each year by the World Economic Forum. Many indicators of subindices (called in GCR reports as "Pillars") of the Global Competitiveness Index – the key integral index of GCR reports are calculated as the quantified answers of survey questions. For example, indicator 2.04 "Efficiency of train services" (Pillar 2 "Infrastructure") is the quantification of responses to the survey question "In your country, how efficient (i.e. frequency, punctuality, speed, price) are train transport services?" The "least efficient" variant of the response "extremely inefficient, among the worst in the world" is scored at 1 point, while the most efficient, "extremely efficient, among the best in the world" is evaluated at 7 points (see in more details Appendix III. Sources and definitions in WEF (2018)).

The final score for the efficiency of train transport services of a specific country is calculated as the weighted (by shares of respondents) sum of scores received from all respondents of the specific country who answered this question. Therefore, the highest possible value of indicator 2.04 "Efficiency of train services" for a specific country is 7.00, while the lowest possible is 1.00. In the last Global Competitiveness Report (WEF, 2018), Switzerland received the highest value of train transport services efficiency among all countries (1st place in the world) at 6.67 points, while the lowest was Lesotho with 1.00 points, 140th place in the world.

The **Integrated BRICS Importance Index** for a thematic field j is calculated as follows: Eq. (2):

$$Integrated\ BRICS\ importance\ index_j = 0.80 \times NII_{BRICS\ average\ j} + 0.15 \times Norm\ ment_{industr\ periodic\ j} + 0.05 \times Norm\ ment_{policy\ docs\ j} \quad (2)$$

$NII_{BRICS\ average\ j}$ – average of values of National Indices of Importance (NII) of all BRICS countries for thematic field j; $Norm\ ment_{industr\ periodics\ j}$ – normalized measure of mentioning of keywords related with thematic field in news articles; $Norm\ ment_{policy\ docs\ j}$ – normalized measure of keyword mentions related with thematic field in English-language strategic STI policy documents of BRICS countries.

Weights for the components of the Integrated BRICS Importance Index are set based on an expert assessment.

For BRICS country i and thematic field j, the **National R&D Capacity Index** (**NRDCI**) is calculated as follows Eq. (3):

$$\mathrm{NRDCI}_{ij} = (RCA\ Index_{ij}^{norm} + RTA\ Index_{ij}^{norm} + CNCI_{ij}^{norm} + Research\ Leadership\ index_{ij} + Collab\ potential\ index_{ij}) \div 5 \quad (3)$$

$RCA\ Index_{ij}^{norm}$ – normalized (across five BRICS countries) Relative Comparative Advantages Index (RCA) (index of scientific specialization) for BRICS country i and thematic field j; $RTA\ Index_{ij}^{norm}$ – normalized (across five BRICS countries) value of Relative Technological Advantages Index (index of technological specialization) for BRICS country i and thematic field j; $CNCI_{ij}^{norm}$ – normalized (across five BRICS countries) value of category normalized citation impact (CNCI)[7] of all publications of BRICS country i on a thematic field j in Web of Science for 2005–2015; $Research\ Leadership\ index_{ij}$ – Research Leadership Index of BRICS country i in thematic field j; $Collab\ potential\ index_{ij}$ – Collaboration Potential Index of BRICS country i in thematic field j (BRICS country's importance index as potential collaboration partner for other BRICS countries).

To set the RCA, RTA, and CNCI indices' maximum value to 1.00 for each specific thematic field, the initial value of all these indices were normalized. Normalization was done as follows: for each specific thematic field, the value of the RCA/RTA/CNCI of the specific BRICS country were divided by the maximum value of the RCA/RTA/CNCI among BRICS countries for this specific thematic field. Formulas for the calculation of the components of NRDCI are given below in Eqs. (6)–(9).

Russian R&D Capacity Index in Comparison with Other BRICS Countries for specific thematic field j ($R\&D\ capacity\ index_{Russia\ vs.\ BRICS\ j}$) is calculated as follows Eq. (4):

$$R\&D\ capacity\ index_{Russia\ vs.BRICS\ j} = \frac{R\&D\ cap\ ind_{diff\ Rus-BRICS\ j} - \min_j R\&D\ cap\ ind_{diff\ Rus-BRICS\ j}}{\max_j R\&D\ cap\ ind_{diff\ Rus-BRICS\ j} - \min_j R\&D\ cap\ ind_{diff\ Rus-BRICS\ j}} \quad (4)$$

where $R\&D\ cap\ ind_{diff\ Rus-BRICS\ j}$ is the measure of differences in values of indices of R&D capacities of Russia and four other BRICS countries (Brazil, India, China, South Africa) in thematic field j. This indicator is calculated as follows Eq. (5):

$$R\&D\ cap\ ind_{diff\ Rus-BRICS\ j} = R\&D\ capacity\ index_{Rus\ j} - R\&D\ capacity\ index_{aver\ other\ BRICS\ j} \quad (5)$$

where $R\&D\ capacity\ index_{Rus\ j}$ – National R&D Capacity Index of Russia in thematic field j; $R\&D\ capacity\ index_{aver\ other\ BRICS\ j}$ – the average value of indices of national R&D capacity of four other BRICS countries (Brazil, India, China, South Africa) in thematic field j.

Relative Comparative Advantages Index (**RCA**) for specific BRICS country (i) and specific thematic field (j) is calculated as follows Eq. (6):

[7] Information on the formulas used for calculating the value of the category normalized citation impact for one document or a group of documents. The methodology for the calculation of the CNCI indicator value for one paper or the set of papers can be found via the link: (cited from Clarivate Analytics, 2018, p. 14)

$$Relative\ comparative\ advantages\ index\ (RCA)_{country\ i\ themat\ area\ j} = \frac{Share\ pub\ WoS_{country\ i\ themat\ area\ j}}{Share\ pub\ WoS_{world\ themat\ area\ j}} \quad (6)$$

$Share\ pub\ WoS_{country\ i\ themat\ area\ j}$ - the share of publications on thematic field j (j = 1, …, 74) in the total number of publications of a specific BRICS country i indexed in Web of Science database for 2012–2016; $Share\ pub\ WoS_{world\ themat\ area\ j}$ – share of publications on thematic field j (j = 1, …, 74) in the global number of publications indexed in Web of Science database for 2012–2016.

Relative Technological Advantages Index (RTA) for a specific thematic field (i) and specific BRICS country (j) is calculated as follows Eq. (7):

$$Relative\ technological\ advantages\ index\ (RTA)_{country\ i\ themat\ area\ j} = \frac{Share\ pat\ Orbit_{country\ i\ themat\ area\ j}}{Share\ pat\ Orbit_{world\ themat\ area\ j}} \quad (7)$$

$Share\ pat\ Orbit_{country\ i\ themat\ area\ j}$ – the share of patent applications in thematic field j (j = 1, …, 74) in the total number of patent applications of BRICS country i registered in the Orbit database for 2005–2015; $Share\ pat\ Orbit_{world\ themat\ area\ j}$ – the share of patent applications in thematic field j (j = 1, …, 74) in the total number of patent applications filled worldwide registered in the Orbit database for 2005–2015.

The methodology for the calculation of the **Category Normalized Citation Impact** (**CNCI**) indicator value for one paper or the set of papers can be described as follows: "Category Normalized Citation Impact (CNCI) of a document is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication, and subject area. When a document is assigned to more than one subject area, an average of the ratios of the actual to expected citations is used. The CNCI for a set of documents, for example, the collected works of an individual, institution, or country, is the average of the CNCI values for all the documents in the set (cited from Clarivate Analytics, 2018, p. 14).

The **Research Leadership Index** of BRICS country i in thematic field j (*Reerach Leadership Index*$_{ij}$) is based on the quantification of the experts' answers to the question "Estimate the S&T capacity of your country comparted with that of countries that are leaders in this thematic field", with four answer options: "On the cutting edge"; "Average performer"; "Lagging behind"; "Difficult to evaluate". For country i and thematic field j this index is calculated as follows Eq. (9):

$$Leadership\ index_{ij} = \frac{N\ resp_{lead\ edge\ ij} \times 1.00 + N\ resp_{aver\ perf\ ij} \times 0.50 + N\ resp_{lag\ beh\ ij} \times 0.00}{N\ resp_{total\ ij} - N\ resp_{diff\ answ\ ij}} \quad (8)$$

$N\ resp_{lead\ edge\ ij}$ – number of respondents from country i who selected "On the cutting edge" option for thematic field j; $N\ resp_{aver\ perf\ ij}$ – number of respondents from country i who selected "Average performer" variant of answer for thematic field j; $N\ resp_{lag\ beh\ ij}$ – number of respondents from country i who selected "Lagging behind" option for thematic field j; $N\ resp_{total\ ij}$ – total number of respondents from country i who answered the question for thematic field j; $N\ resp_{diff\ answ\ ij}$ - number of respondents from country who selected "Difficult to evaluate" option for thematic field j.

The **Collaboration Potential Index** of BRICS country i in thematic field j (*BRICS collab partners index*$_{ij}$) is based on the quantification of the surveyed experts' answers to the question "For this thematic field select no more than two BRICS countries who in your opinion have the best prospects for scientific collaboration". For country i and thematic field j this index is calculated as follows Eq. (9):

$$BRICS\ collab\ partners\ index_{ij} = \frac{N\ resp_{country\ ij}}{\max_i N\ resp_{country\ ij}} \quad (9)$$

$N\ resp_{country\ ij}$ – the number of respondents who selected country i in his/her answer for thematic field j when answering question "For this thematic field select no more than two BRICS countries who in your opinion have the best prospects for scientific collaboration"; $\max_i N\ resp_{country\ ij}$ - BRICS country selected by the maximum number of respondents for thematic field j when answering question "For this thematic field select no more than two BRICS countries who in your opinion have the best prospects for scientific collaboration".

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Professor **Alexander Sokolov** is the Deputy Director of the Institute for Statistical Studies and Economics of Knowledge and Director of the International Foresight Centre at the National Research University Higher School of Economics. He has authored over 140 publications in Russia and internationally. The main field of his research is foresight and innovation policy. Alexander Sokolov has managed many large-scale foresight projects in Russia including “Identification of National S&T Priorities and Critical Technologies” and several national S&T foresight studies. He also participates in many international projects and is a member of expert groups at the OECD, UNIDO, and other international organizations.

Dr. **Sergey Shashnov** is Head of Department for Strategic Foresight of the Institute for Statistical Studies and Economics of Knowledge at National Research University Higher School of Economics, Moscow. Dr. Shashnov has a long experience in organizing and conducting long-term forecast and foresight studies, development of industry-specific Foresight methodologies, statistics and expert surveys in the field of science, technology and innovation, as well as socio-economic issues, analytical work, the analysis and generalization of statistical and sociological data. Sergey Shashnov has authored more than 40 publications in Russia and internationally. The main topics of his research are: the methodology of analysis and forecasting of scientific and technological development, priorities setting for scientific and technological development.

Maxim Kotsemir is Research Fellow of Quantitative Modelling Unit of the Institute for Statistical Studies and Economics of Knowledge, National Research University Higher School of Economics (ISSEK HSE), Moscow. The key fields of interest of his research are: scientometrics; innovation studies, forecasting. During the work in ISSEK HSE Maxim Kotsemir prepared more than 30 publications – articles in Russian and foreign journals indexed in Scopus and Web of Science, working papers, statistical digests, analytical reports.

Anna Grebenyuk is Deputy Head of the Department for Strategic Foresight, Institute for Statistical Studies and Economics of Knowledge, Department for Private-Public Partnership in Innovation Sector, National Research University Higher School of Economics, Moscow, Russia. Anna Grebenyuk is author of more than 15 publications in fields of foresight and STI policy studies.