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# Contrasting High Scientific Production with Low International Collaboration and Scientific Impact: The Brazilian Case

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## Abstract

The article presents an analysis of scientific production and impact among 35 most productive countries in the world. In the period 2000–2016, these countries produced 92% of the world publications. A correlation of international collaboration and scientific impact is shown. Differently from this pattern, Brazil shows high quantitative performance but low scientific impact, which is attributed to its low level of international collaboration. By contrast, instead of a generalized cooperation, as many undeveloped countries do, Brazil uses its internal effort to explore cooperation in a more symmetrical manner. Thus, in several areas, Brazil occupies a prominent position, including technological sectors, enabling it to occupy the eighth world's economy position. The data confirm that an efficient internal scientific effort combined with well-balanced international cooperation can be more effective to enable countries to achieve higher levels of development in order to meet their technical and socioeconomic challenges. Brazil was able to reach the first step but did not follow the same track concerning higher scientific impact.

**Keywords:** scientometric analysis, international scientific collaboration, impact, BRICS, Latin American countries

## 1. Introduction

Collaboration is irreversibly present in scientific practice. The idea that collaboration contributes to increase scientific productivity has already been addressed at national and international levels. It can be said that collaboration is a phenomenon accepted by the scientific community and stimulated by development agencies, as emphasized by Katz and Martin [1]. In fact, international scientific collaboration network has been growing even fast in recent years [2, 3]. This practice occurs in the social context of individual behavior, and it is, therefore, a complex phenomenon defined as the interaction between two or more groups of scientists, which provides the sharing of activities in the sense of achieving common goals [4].

Scientific collaboration can also show negative aspects when, for instance, collaboration occurs among researchers in an unethical manner as for the case of animals and even human tests made in less developed countries, since this type

of experiment is prohibited in advanced countries. Collaboration can also exert a “lobbying” power by influencing political decisions for the release of funds, benefiting only some groups to the detriment of others working on the same theme [4]. The author emphasizes, however, that the final stage of a successful collaboration is co-authoring articles, because the dissemination of results through scientific publication is, in fact, the traditional result of research. Furthermore, international collaboration feeds other studies and new projects, which strengthen scientific communities. In addition, the publication is a proof of the good utilization of the financial resources used in research that generate new knowledge.

The productivity of Brazilian science, including aspects of international scientific collaboration, has been studied by several authors. Some years ago, Leta and Chaimovich [5] carried out a study on the size of Brazilian production in relation to the rest of the world, covering the period 1981–2000. The researchers showed that in the period studied, the countries that had more scientific collaboration with Brazil were from Europe and North America. While, with the United States, such collaboration reached 40.5%, the number of collaborative publications with Latin American countries represented less than 10%. The data indicate, for that time, the trend that in developing countries, collaboration tended to be more intense with more developed countries. It was also clear that international collaboration benefited the production and visibility of publications from lesser developed countries. Glänzel and Schubert [6] revealed some facets of scientific collaboration including Brazilian data. According to the authors, collaboration in domestic co-authorship is clearly influenced by two factors: (i) the size of the scientific community in the country (evidenced in the scientific production of the United States and the United Kingdom), since in these countries it is easier for a researcher to find scientific partners than for researchers working in a small country, and (ii) cultural reasons, such as geography, language, politics, or comparative advantage. However, the authors point out some situations which are not included in these rules, as is the case in some typically international countries that conduct research with high level of scientific domesticity (such as Hungary in agriculture and environment or the Czech Republic in neuroscience and behavior). Conversely, there are other cases where a large country is low in scientific domesticity (e.g., China in the areas of agriculture and the environment) [6].

Other aspects of scientific collaboration raised by Vanz [7] and Vanz and Stumpf [8] show that in Brazilian research, as in other countries, collaboration promotes access to equipment and materials, allowing sharing of scientific knowledge and greater specialization of research groups. In addition, they affirm that the results of a published work in co-authorship are more likely to be accepted and obtain a greater number of citations when compared to works published individually. The authors also point out that good communication between researchers, sharing of social skills, and the ability to conduct teamwork are fundamental characteristics for the success of scientific collaboration, especially when it involves geographical distances and needs of a better understanding of concepts and methodologies and when collaboration involves researchers from different areas [8]. Santin, Vanz, and Stumpf [9] point out the predominance of bilateral collaboration in the Brazilian production of articles in *Evolutionary Biology* published in the period 2004–2006. Though using old data, it should be noted that the authors selected one of the few areas in which Brazil has the highest index of international collaboration. As a fairly new area in the world scientific scenario, *Evolutionary Biology* attracts a high level of international cooperative research. In this specific case, most of the articles resulting from Brazilian researchers had the participation of co-authors from some other countries. The authors point out that 47% of the Brazilian publications in this field included researchers from the United States, United Kingdom, France, and

Germany, while only 5% were from Argentina. The data indicate the preference for international collaboration with developed countries, thus not only confirming the findings shown by Leta and Chaimovich [5] but also revealing that collaboration with neighboring countries, such as Argentina, is practically negligible.

The above studies do not include cases of “naturally forced” cooperation driven by the necessity to enable mutual technological advances between more developed countries and even competitors in the field of innovation. Furthermore, the issue of international collaboration has not been addressed for other factors exerting attraction for collaboration. For example, in Brazil, the possibility of making domestic science is more visible, such as in the areas of biodiversity and tropical medicine, agriculture, biotechnology, and bioeconomy, which are research fields with a strong attractiveness for international collaborators. Contrarily, in this sense, Brazil is a typical case where Brazilian scientists cite more than they are cited. In fact, the feature of low quotation between peers seems to permeate and constitutes a challenge for scientists not only in Brazil but throughout Latin America since long ago [10], which is still a reality today.

A comparison of the production and scientific collaboration of the countries of the BRICS group was made by Finardi [11] and Finardi and Buratti [12]. The studies highlighted the importance of international collaboration in the scientific production of these countries. The authors emphasize that the relationship between countries is strengthened not only in economic aspects but also in relation to the scientific partnerships. They firstly analyzed the intra-BRICS collaboration and compared the relative strength of relations between the member countries. Secondly, the authors sought to understand the pattern of collaboration of the BRICS countries in relation to that with other collaborative countries, regardless of the direction of the partnerships. The data showed that the intra-BRICS collaborations are weaker than the collaborations with the other countries studied. The results indicate that it would be relevant to plan policies aimed at promoting scientific collaboration among the five countries, such as fostering scientific research, and this is generally considered a strategic measure for a country's growth. Therefore, improving the level of collaboration among the five BRICS countries could make it possible to have positive effects on the social and economic development as desired by developing countries.

The finding that intra-BRICS collaboration, that is, collaboration between Brazil, Russia, India, China, and South Africa, has been shown to be weaker than with the rest of the world was also studied by Bouabid, Paul-Hus, and Larivière [3]. The authors studied the productivity evolution of the G7 member countries, formed by the United States, Germany, Canada, France, Italy, Japan, and United Kingdom, in relation to BRICS member countries. They compared production and scientific collaboration in fields employing high technologies such as engineering, medical sciences, earth sciences, and space sciences and found that the scientific activities of BRICS are reinforced by high-technology exports upon their collaboration with the G7 countries. While the high-technology exports made by most BRICS countries to the G7 countries increased over the period studied, compared to the flow of these exports among the BRICS countries, these collaborations remained very weak. By extension, it can be seen that the same phenomenon occurs with the scientific collaboration between the countries of Latin America. In other words, the scientific collaboration continues to be lower than the rates of collaboration with the most productive central countries. A study about collaboration and scientific impact of Latin American countries in the area of biotechnology found that the increase in research in this sector originates from international collaboration, especially with the more developed countries, those occupying the influential positions in the area, such as the United States, Japan, Germany, England, Spain, and France [13]. The authors emphasize that, in a network of scientific collaboration, it is not only

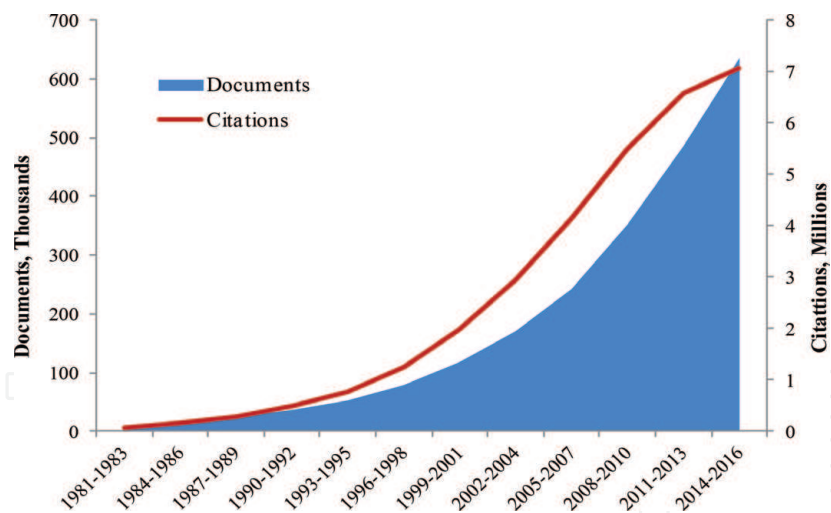


important to have a good production and impact but to have the capacity to become a mediator or link in establishing collaboration between the countries participating in the productive research network. In this way, the research groups from the less developed countries that make this communication bridge increase their capacities to absorb resources have access to new technologies and resources at high-technology laboratories, thus increasing the quality of their results. The observations derived from the studies with BRICS and Latin American countries were confirmed in our work with actualized data showing, once again, that either for historical, cultural, or economic reasons, scientific collaboration and consequently the development of the member countries of these groups will not occur as a result of intragroup collaboration, but instead, mainly with the most productive countries. Furthermore, despite the recognized advantages of international cooperation, we have shown in a previous article [14] that countries that have not prepared themselves to exploit the opportunities offered by international collaboration do not internalize these advantages for their own best technical-scientific and economic benefit.

As compared to previous studies, in the present work, we explore several new aspects, including (i) a much longer and recent studied period, (ii) the evolution of Brazilian scientific productivity and of its most significant areas, (iii) correlation between the number of graduate programs and the number of research groups, and (iv) correlation between international collaboration and citation impact of the 35 countries with high scientific productivity. Thus, the aim of the present work is to demonstrate the influence of international collaboration on the scientific impact generated by the citations in four aspects: (a) in the comparison between the 35 most productive countries, a small group of countries (about 17% of the world countries listed in the ESI database), which includes Brazil, that produce 92% of the world publications; (b) comparing Brazil with the most productive Latin American countries; (c) the position of Brazil among the countries of the BRICS group (Brazil, Russia, India, China, and South Africa), and (d) contrasting Brazil's low international cooperation and consequent lower scientific impact with its recognized technological performance in several applied fields such as tropical agriculture, technology for exploiting petroleum resources in deep sea water, woodland recovery of once infertile land ("cerrados"), cellulose and paper mill industry, sophisticated bank automation, construction of alcohol-propelled motor vehicles, aircraft design, and industrial production, among others [15]. The study uses comparative analysis among the most productive countries. For this purpose, data were collected on the scientific performance of the countries in the 22 areas of the Essential Science Indicators (ESI), where all countries listed in the InCites database (Thomson Reuters 2016) are represented. It is important to note that the metrics used in InCites, although not frequently used in Brazil, are widely recognized for comparative studies. According to Bornmann and Leydesdorf [16] with InCites, it is possible to study the impact and the citation behavior of countries using a time window for a long period of publications, thus allowing to compare areas with normalized indicators in an efficient manner.

## 2. Methodology

The article results from a scientometric study through the analyses of bibliographic indicators extracted from recognized databases, described below. International collaboration and other indicators were obtained through the survey of InCites platform, a fully integrated Web of Science (WoS) database. This analytic tool is under the responsibility of former Thomson Reuters (now Clarivate Analytics), Philadelphia/USA, available through institutional subscription and internal access in the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).



**Figure 1.**  
*Brazilian scientific production: accumulated number of articles and citations. Source: InCites dataset updated 2017-10-14. Includes Web of Science content indexed through 2017-10-3.*

The InCites Platform is composed of several other databases. In this study, we selected the Essential Sciences Indicators (ESI), which classifies scientific production in 22 areas of knowledge. Bibliographical data in these areas of ESI include articles and reviews of the Science Citation Index Expanded and the Social Science Citation Index, but do not include the indexed papers of Arts and Humanities, Conference Proceedings Citation Index, and Book Citation Index. ESI is part of the InCites platform and a filter for large areas of knowledge, making it easier to compare them. Each journal that makes up the ESI database is classified in only one area, with no overlap of subjects, or double counting of articles between areas. When the journal is classified as multidisciplinary (as science or nature, for instance), the system makes a disambiguation of the theme of an article by the topics of the journals cited in this one, so if the article published in one of these journals refers to a certain theme, the references will confirm in which of the 22 areas the article in question will be indexed. Except for the accumulated data shown in **Figure 1** and **Table 1** where the numbers started in the trimester 1981–1983, the present study covered a period of 17 years (between 2000 and 2016). The data were downloaded and worked with Excel listing the following indicators:

1. Articles or documents: Number of published papers, including articles, full proceeding papers, and reviews.
2. Times cited: Number of citations received during the period.
3. % Documents cited: percentage of cited documents as a fraction of total documents in the period.
4. Citation impact: Average number of citations received by the publications (or area) in a given period. It is the result of the division of the total number of citations by the total number of publications in the period.
5. Impact relative to world (IRW): It concerns to the impact of an area or country relative to the world's average impact of that area or the average of all countries together. An IRW index greater than 1.0 indicates that impact in a specific area or country is larger than the average impact of all areas together and, in the case of countries, that the impact of a country is higher than the average of all countries [14].

6. International collaboration: Number of documents in international co-authoring.
7. Percentage of international collaboration: Proportion of documents published in international co-authoring in relation to the total number of publications.

| No.           | Areas                          | 1981–1983   |              |                  | 2014–2016      |              |                  | Growth number doc. |
|---------------|--------------------------------|-------------|--------------|------------------|----------------|--------------|------------------|--------------------|
|               |                                | N. doc.     | IRW          | % Doc. in top 1% | N. documents   | IRW          | % doc. in top 1% |                    |
| 1             | Agricultural sciences          | 700         | 0.294        | 0.6              | 13,181         | 0.517        | 0.6              | 17.8               |
| 2             | Biology and biochemistry       | 550         | 0.724        | 0.0              | 7461           | 0.907        | 0.4              | 12.6               |
| 3             | Chemistry                      | 533         | 0.822        | 0.4              | 10,824         | 1.066        | 0.1              | 19.3               |
| 4             | Clinical medicine              | 1811        | 0.344        | 0.4              | 33,287         | 0.846        | 1.1              | 17.4               |
| 5             | Computer science               | 43          | 0.866        | 0.0              | 3169           | 0.581        | 0.5              | 72.7               |
| 6             | Economics and business         | 42          | 1.155        | 0.0              | 1154           | 0.402        | 0.7              | 26.5               |
| 7             | Engineering                    | 189         | 0.589        | 0.5              | 7562           | 0.777        | 0.5              | 39.0               |
| 8             | Environment/ecology            | 91          | 0.748        | 0.0              | 5804           | 1.152        | 1.3              | 62.8               |
| 9             | Geosciences                    | 185         | 0.905        | 0.5              | 2961           | 0.916        | 0.6              | 15.0               |
| 10            | Immunology                     | 86          | 1.680        | 0.0              | 3772           | 1.204        | 1.2              | 42.9               |
| 11            | Materials science              | 38          | 0.475        | 2.6              | 4697           | 0.826        | 0.2              | 122.6              |
| 12            | Mathematics                    | 241         | 0.993        | 1.2              | 3179           | 0.398        | 0.4              | 12.2               |
| 13            | Microbiology                   | 82          | 1.401        | 0.0              | 2913           | 1.089        | 0.8              | 34.5               |
| 14            | Molecular biology and genetics | 184         | 0.949        | 0.0              | 4244           | 1.105        | 0.7              | 22.1               |
| 15            | Multidisciplinary              | 282         | 0.066        | 0.7              | 232            | 0.931        | 1.3              | −0.2               |
| 16            | Neuroscience and behavior      | 100         | 1.790        | 1.0              | 5400           | 0.987        | 0.6              | 53.0               |
| 17            | Pharmacology and toxicology    | 129         | 1.070        | 0.0              | 4990           | 0.765        | 0.5              | 37.7               |
| 18            | Physics                        | 723         | 1.210        | 0.6              | 8146           | 1.589        | 1.8              | 10.3               |
| 19            | Plant and animal science       | 659         | 0.530        | 0.2              | 17,719         | 0.534        | 0.6              | 25.9               |
| 20            | Psychiatry/psychology          | 115         | 0.214        | 0.0              | 2433           | 0.866        | 1.5              | 20.2               |
| 21            | Social sciences, general       | 363         | 0.483        | 1.4              | 6837           | 0.381        | 0.7              | 17.8               |
| 22            | Space science                  | 109         | 1.429        | 0.0              | 1493           | 2.676        | 3.4              | 12.7               |
| <b>Brazil</b> |                                | <b>7255</b> | <b>0.649</b> | <b>0.4</b>       | <b>149,787</b> | <b>0.862</b> | <b>0.8</b>       | <b>19.6</b>        |

Comparison of the two distant triennials: 1981–1983 and 2014–2016. Source: exported date 2017-10-13. InCites dataset updated 2017-09-23. Includes Web of Science content indexed through 2017-07-31.

**Table 1.**  
 Growth of the Brazilian scientific production of all ESI areas.

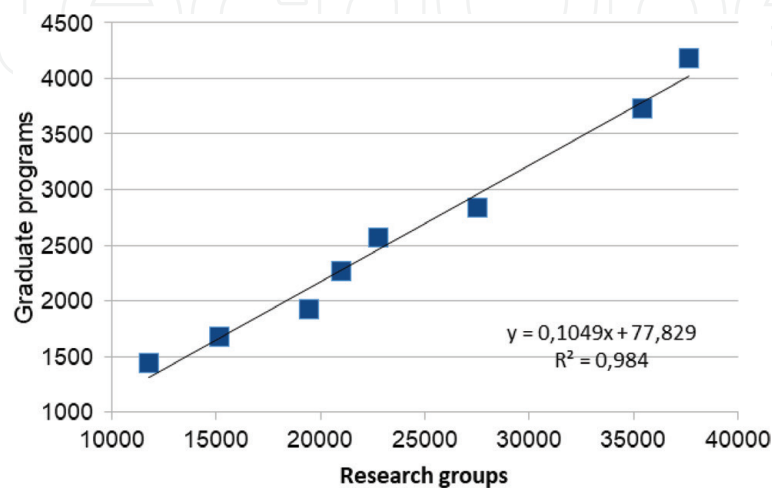
3. Results and discussion

Despite its late entry into the world’s science circle, in the last decades, Brazil has been experiencing extraordinary growth in the production of indexed scientific articles published in periodicals with international qualification. In the 1960s, the

average of scientific publications published in periodicals indexed in the database of the former Institute for Scientific Information (ISI) was 52 scientific articles annually; in 1970 there were only 64 articles, representing 0.019% of world production, jumping to 10,555 complete articles in 2001 [17, 18]. At present (2012–2016), Brazil publishes on average ca. 50,000 articles per year. **Figure 1** shows the evolution of the Brazilian scientific production covering all the 12 trimesters (from 1981 to 1983 up to the present 2014–2016). The data report the accumulated growth of published articles as well as that of accumulated citations. The amount of documents published in the period accounts for a total of 636,000, while that of citations reached more than 7 million, which indicates an average of 11.1 citations per article (impact) for the whole period. This manner of representing the mean impact is thought by the authors to be more adequate than that commonly used (year by year) way because, as it is well known, citations of recent papers (less than 8–10 years) are small, resulting in a low index of the impact factor, a common feature applied to all fields and world science [19].

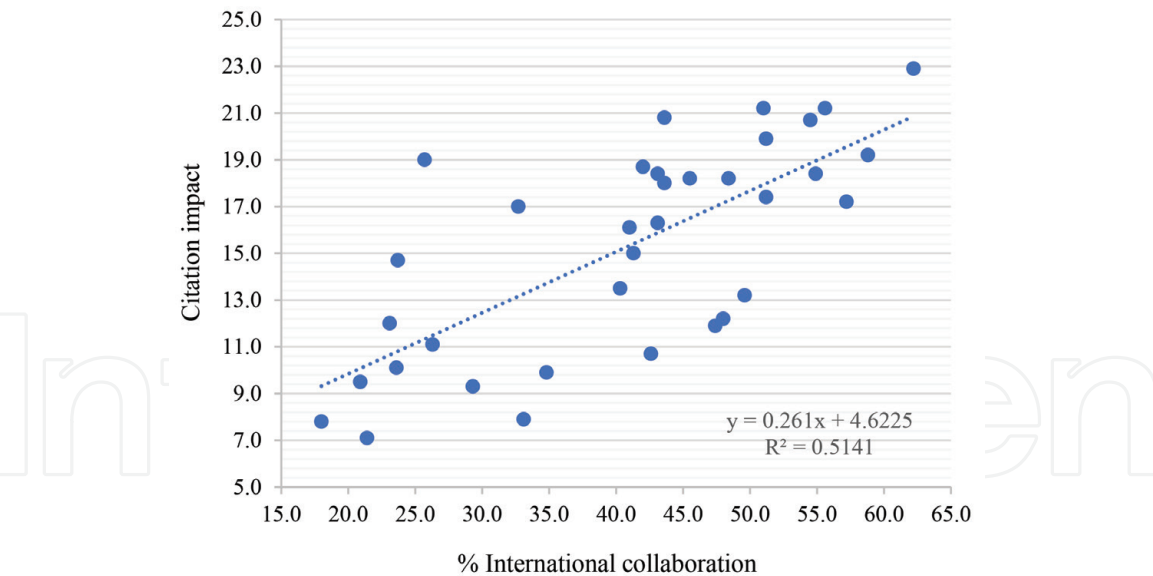
As seen in **Table 1**, except for the multidisciplinary field, an expressive growth is found in all research areas in Brazil. On average, between the first triennial (1981–1983) and the last one (2014–2016), there was a growth of 20-fold for the total number of articles, where some areas such as materials science (123-fold), computer science (73-fold), environment and ecology (63-fold), and neuroscience and behavior (53-fold) show much higher growth. It is also seen in the table that the other indicators, the impact relative to world (IRW), increased from 0.65 to 0.86 and the percentage of top 1% articles from 0.4 to 0.8%.

The evolution of Brazilian scientific production occurred within a period of only 35 years and allowed Brazil to be included, in 2009, among the top 20 scientifically most productive countries. This time period is coincident with that followed after the foundation of the Ministry of Science and Technology (MCT, today MCTIC) in 1985. The rapid development of scientific activities in Brazil was based on the establishment of a vigorous postgraduate program [15], which began in the late 1960s and resulted in the consolidation of the current 37,640 research groups registered in the country and covering all scientific areas [20]. **Figure 2** illustrates the recent growth of the Brazilian graduate programs, and **Figure 3** illustrates the evolution and consolidation of research groups. As it can be seen, there is a parallelism among the indicators of the three growth curves covering the period studied. This growth also correlates well with increasing



**Figure 2.** Correlation between the number of graduate programs and the number of research groups in Brazil—2000–2016. Source: CAPES. Geocapes. <http://geocapes.capes.gov.br/geocapes2/> and CNPq (2017). Estatísticas CNPq. <http://estatisticas.cnpq.br/>.





**Figure 3.** Correlation between % international collaboration and citation impact of the 35 countries with high scientific productivity (2000–2016). Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

funding from the federal agencies CAPES, CNPq, and FINEP and especially with that of state agencies FAPESP, FAPEMIG, and FAPERJ in the period (data not shown). It was also positively influenced by the availability of The Portal of Periodicals by CAPES in 2001 [18].

In order to compare Brazil with other countries, in this study we also explore some characteristics of world scientific production in the period 2000–2016. **Table 1** lists the 35 countries with the largest number of articles in WoS, i.e., countries with a contribution of at least 0.5% of the world production which account for 92.2% of the world total scientific production in the period (**Table 2**). Brazil presently ranks 14th. While the table includes all BRICS countries, from Latin America only Brazil and Mexico appear. Other quantitative and qualitative bibliometric studies are also presented in **Table 2**. In the period 2000–2016, the world scientific production reached 26,103,636 articles, while the 35 most productive countries totaled 28,671,597 documents. This quantitative artifact is due to the phenomenon known as double counting [14, 18], which occurs, in this comparison, whenever the sum of publications is counted country by country, since articles with co-authorship including authors from two or more countries are counted at least twice. It was found in a previous study [14], covering the period 2011–2014, that double counting corresponded, in the period, to 33.1% of world production. Here, double counting of articles reaches 16.1% (**Table 2**). This discrepancy is due to the coverage for a longer period of years in the present article, since it is known that the indexes of international collaboration that affect double counting have been increasing in recent years. After correction, the total of articles in the 35 countries of **Table 1** corresponds, in the period, to 24,055,470 or 92.2% of the world total without double counting. Therefore, the data indicate that the countries in **Table 2**, which represent 17% of world countries, constitute an adequate sample for the present bibliometric study.

**Table 2** also shows a high percentage of cited articles (average of 73.3%), with small individual variation: 65.9% (Russia) to 79.4% (Finland), all above the world average 66.5%. These indices are reflected in a high total of citations which in turn produces an average impact index of 16.3 which is 1.2 times higher than the world average index (13.5).

| Country       | Rank | Articles  | Times cited | % Doc. Cited | Citation impact | International collaborations | % International collaborations |
|---------------|------|-----------|-------------|--------------|-----------------|------------------------------|--------------------------------|
| United States | 1    | 7,923,518 | 150,865,186 | 67.5         | 19.0            | 2,038,606                    | 25.7                           |
| China         | 2    | 2,275,635 | 23,014,726  | 73.9         | 10.1            | 537,660                      | 23.6                           |
| Germany       | 3    | 1,829,635 | 34,150,179  | 70.1         | 18.7            | 768,571                      | 42.0                           |
| England       | 4    | 1,814,621 | 32,931,581  | 73.2         | 18.2            | 824,910                      | 45.5                           |
| Japan         | 5    | 1,555,919 | 22,874,614  | 74.5         | 14.7            | 368,209                      | 23.7                           |
| France        | 6    | 1,231,668 | 22,351,252  | 75.9         | 18.2            | 596,112                      | 48.4                           |
| Canada        | 7    | 1,109,651 | 20,003,328  | 72.9         | 18.0            | 484,151                      | 43.6                           |
| Italy         | 8    | 1,051,109 | 16,907,001  | 74.1         | 16.1            | 430,418                      | 41.0                           |
| Spain         | 9    | 837,380   | 12,579,920  | 73.9         | 15.0            | 345,891                      | 41.3                           |
| Australia     | 10   | 822,175   | 13,371,337  | 73.1         | 16.3            | 354,313                      | 43.1                           |
| India         | 11   | 713,637   | 6,808,521   | 72.2         | 9.5             | 148,773                      | 20.9                           |
| Korea         | 12   | 691,631   | 7,650,919   | 72.0         | 11.1            | 182,056                      | 26.3                           |
| Netherlands   | 13   | 629,561   | 13,319,873  | 75.3         | 21.2            | 320,978                      | 51.0                           |
| Brazil        | 14   | 539,049   | 4,997,160   | 69.5         | 9.3             | 158,083                      | 29.3                           |
| Russia        | 15   | 510,662   | 4,039,770   | 65.9         | 7.9             | 168,817                      | 33.1                           |
| Switzerland   | 16   | 448,485   | 10,283,870  | 76.1         | 22.9            | 279,150                      | 62.2                           |
| Sweden        | 17   | 407,754   | 8,438,475   | 78.1         | 20.7            | 222,203                      | 54.5                           |
| Taiwan        | 18   | 386,178   | 4,638,999   | 77.3         | 12.0            | 89,180                       | 23.1                           |
| Turkey        | 19   | 378,817   | 2,963,670   | 65.9         | 7.8             | 68,318                       | 18.0                           |
| Poland        | 20   | 353,032   | 3,498,064   | 70.7         | 9.9             | 122,718                      | 34.8                           |
| Belgium       | 21   | 335,616   | 6,431,262   | 75.7         | 19.2            | 197,217                      | 58.8                           |
| Scotland      | 22   | 266,900   | 5,541,755   | 73.7         | 20.8            | 116,315                      | 43.6                           |
| Iran          | 23   | 259,961   | 1,834,821   | 68.7         | 7.1             | 55,688                       | 21.4                           |

| Country   | Rank | Articles   | Times cited | % Doc. Cited                   | Citation impact | International collaborations | % International collaborations |
|---|------|------------|-------------|--------------------------------|-----------------|------------------------------|--------------------------------|
| Denmark   | 24   | 248,517    | 5,266,614   | 76.4                           | 21.2            | 138,171                      | 55.6                           |
| Israel  | 25   | 241,825    | 4,458,141   | 75.8                           | 18.4            | 104,323                      | 43.1                           |
| Austria   | 26   | 240,026    | 4,136,021   | 71.9                           | 17.2            | 137,232                      | 57.2                           |
| Greece  | 27   | 194,490    | 2,618,069   | 72.6                           | 13.5            | 78,315                       | 40.3                           |
| Finland   | 28   | 194,118    | 3,861,474   | 79.4                           | 19.9            | 99,452                       | 51.2                           |
| Hong Kong   | 29   | 180,864    | 3,077,238   | 79.0                           | 17.0            | 59,202                       | 32.7                           |
| Mexico  | 30   | 175,970    | 1,886,483   | 69.9                           | 10.7            | 74,953                       | 42.6                           |
| Portugal  | 31   | 175,260    | 2,317,498   | 71.7                           | 13.2            | 86,924                       | 49.6                           |
| Norway  | 32   | 175,131    | 3,224,102   | 77.7                           | 18.4            | 96,192                       | 54.9                           |
| Czech Republic  | 33   | 163,456    | 1,944,604   | 72.3                           | 11.9            | 77,412                       | 47.4                           |
| Singapore   | 34   | 162,098    | 2,818,900   | 77.7                           | 17.4            | 83,015                       | 51.2                           |
| South Africa  | 35   | 147,248    | 1,800,982   | 71.4                           | 12.2            | 70,708                       | 48.0                           |
| Total and average   |      | 28,671,597 | 466,906,409 | 73.3                           | 15.3            | 9,984,236                    | 40.8                           |
| World (without double counting)   |      | 26,238,799 | 354,501,667 | 66.5                           | 13.2            | —                            | 18.0                           |
| World (with double counting)  |      | 31,110,404 |             | Percent double counting: 16.1% |                 |                              |                                |
| Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03. |      |            |             |                                |                 |                              |                                |

**Table 2.**  
Scientific performance of the 35 most productive countries in 2000–2016.

On the other hand, it can be observed in the table that the robust quantitative data of the scientific production of the 35 countries conceal the dispersion of the most important qualitative components of this ranking: the scientific impact (Switzerland 22.9, Iran 7.1) and international collaboration (Switzerland, 62.2%, Turkey, 18.0%), with the average for the 35 countries of 15.3 and 40.8%, respectively, for the two indicators. It should be mentioned that when the data of the most recent year (2016) is taken, the international cooperation index of Switzerland increases from 62.2 to 72.1%, Turkey from 18.0 to 21.1%, and the average of the 35 countries from 40.8 to 49.9% (data not shown), thus confirming the recent tendency for the growth of international collaboration among countries. Analyzing the impact ranking (numbers in brackets in the column), a different figure is shown where the first ten countries in number of publications do not appear in a similar position in the impact ranking. Here, the first seven positions are occupied by Switzerland, Denmark, the Netherlands, Scotland, Sweden, Finland, and Belgium; none of them is present in the first quantitative positions, but all of them are showing a high proportion of international collaboration, thus indicating again the correlation—high international collaboration and higher citation impact—as shown in **Figure 3**.

**Table 3** clearly illustrates the influence of international cooperation on the index of scientific impact of the countries. Here we can see that the 21 countries with the highest international collaboration rates (above the average of **Table 2**, or 40.8%), varying between 41.3% (Spain) and 62.2% (Switzerland), have an average impact well above the mean of all countries. In this group, only the United States (25.7%) and Hong Kong (32.7%) have international cooperation level below average. The average impact index of the 21 countries in this group is 17.9 and the international collaboration is 49.2%. On the other hand, among the 14 other countries with the lowest impact rates, only Mexico has international collaboration above the average of the 35 countries. In this second group, the average impact index of the 14 countries is 11.4 and the international collaboration is 28.3%. The indices of the countries in the first group are, respectively, 57 and 74% higher than those in the second group, confirming again this positive correlation: high international collaboration, higher citation impact. Brazil is located in the group of countries that cite more than they are cited [10]. As with most countries with a low level of international cooperation, Brazil's low impact index (9.3), one of the lowest among the 35 most productive countries, is, in turn, followed by a low percentage (29.3%) of international scientific collaboration, also of the lowest in the whole world.

This work also included comparative studies with countries in Latin America, some of them linked to the MERCOSUL agreement and the component countries of the BRICS group. Both consort of countries present common commercial and social interests including the perspective of presenting some level of scientific collaboration. The comparison of Brazil with other Latin American countries is shown in **Table 4** which presents the data of the scientific production of the 12 most productive countries of Latin America in the period 2000–2016. This group includes members of the MERCOSUL: Argentina, Brazil, Chile (associated), Uruguay, and Venezuela (suspended in 2016). The evolution of the percentage of international collaboration in the period studied for the five most productive countries in the region is shown in **Figure 4**. Taken in consideration the number of WoS indexed publications shown in **Table 4**, it is seen that Brazil alone responds for more than 50% of publications of the 12 countries. It is also seen that half of these countries produced in the large period analyzed a small number of publications having all of them a very high percentage (64.4–86.3%) of international collaboration. The average percentage of cited articles in the 12 countries (71.1%) is relatively high compared to the world, and this high value is in agreement with that of the scientific impact (13.3). The variation in international collaboration ranged from 29.3 to 86.3%, with a high



| More than 41% of international collaboration |                |                 |      |                                | Less than 41% of international collaboration |                 |      |                                |
|--|----------------|-----------------|------|--------------------------------|--|-----------------|------|--------------------------------|
| N.   | Country        | Citation impact | Rank | % International collaborations | Country                                      | Citation impact | Rank | % International collaborations |
| 1  | Switzerland    | 22.9            | 1    | 62.2                           | United States                                | 19.0            | 8    | 25.7                           |
| 2  | Denmark        | 21.2            | 2    | 55.6                           | Hong Kong                                    | 17.0            | 17   | 32.7                           |
| 3  | Netherlands    | 21.2            | 3    | 51.0                           | Japan  | 14.7            | 21   | 23.7                           |
| 4  | Scotland       | 20.8            | 4    | 43.6                           | Greece                                       | 13.5            | 22   | 40.3                           |
| 5  | Sweden         | 20.7            | 5    | 54.5                           | Taiwan                                       | 12.0            | 25   | 23.1                           |
| 6  | Finland        | 19.9            | 6    | 51.2                           | Korea  | 11.1            | 27   | 26.3                           |
| 7  | Belgium        | 19.2            | 7    | 58.8                           | Mexico                                       | 10.7            | 28   | 42.6                           |
| 8  | England        | 18.7            | 9    | 42.0                           | China  | 10.1            | 29   | 23.6                           |
| 9  | Israel         | 18.4            | 10   | 43.1                           | Poland                                       | 9.9             | 30   | 34.8                           |
| 10   | Norway         | 18.4            | 11   | 54.9                           | India  | 9.5             | 31   | 20.9                           |
| 11   | Germany        | 18.2            | 12   | 45.5                           | Brazil                                       | 9.3             | 32   | 29.3                           |
| 12   | France         | 18.2            | 13   | 48.4                           | Russia                                       | 7.9             | 33   | 33.1                           |
| 13   | Canada         | 18.0            | 14   | 43.6                           | Turkey                                       | 7.8             | 34   | 18.0                           |
| 14   | Singapore      | 17.4            | 15   | 51.2                           | Iran   | 7.1             | 35   | 21.4                           |
| 15   | Austria        | 17.2            | 16   | 57.2                           | —  | —               | —    | —                              |
| 16   | Australia      | 16.3            | 18   | 43.1                           | —  | —               | —    | —                              |
| 17   | Italy          | 16.1            | 19   | 41.0                           | —  | —               | —    | —                              |
| 18   | Spain          | 15.0            | 20   | 41.3                           | —  | —               | —    | —                              |
| 19   | Portugal       | 13.2            | 23   | 49.6                           | —  | —               | —    | —                              |
| 20   | South Africa   | 12.2            | 24   | 48.0                           | —  | —               | —    | —                              |
| 21   | Czech Republic | 11.9            | 26   | 47.4                           | —  | —               | —    | —                              |
| Average                                      |                | 17.9            | —    | 49.2                           | Average                                      | 11.4            | —    | 28.3                           |

Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

**Table 3.**  
*Influence of the international collaboration on the scientific impact of countries: 2000–2016.*

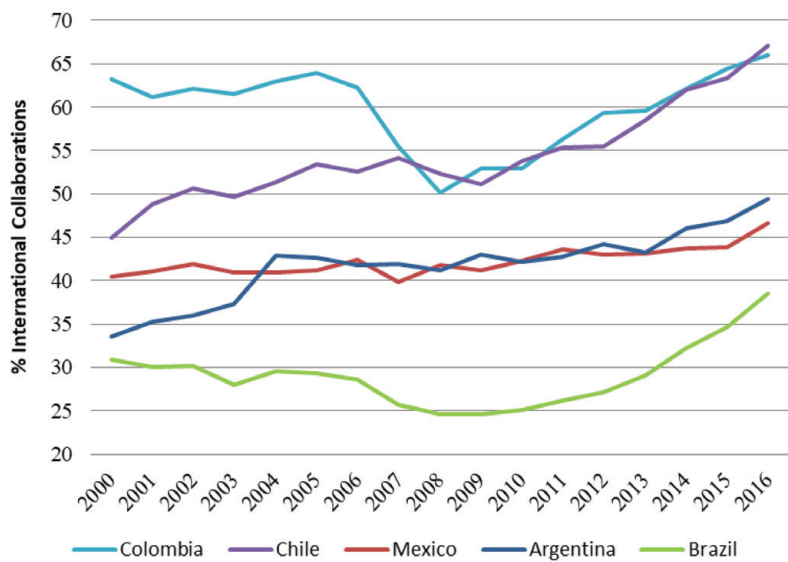
average rate (61.5%). Brazil, despite its higher production, has the lowest impact rate (9.3) and international collaboration (29.3%) level. Contrasting with their rate of publications, the countries with the highest impact rates also present the highest levels of international collaboration, confirming the observation that there is an intrinsic relationship between these two indicators. Thus, in comparison with the most productive Latin American countries, Brazil is behind the other countries of the group reinforcing the significant observation: greater proportion of international collaboration, higher index of scientific impact [14].

However, according to recent studies [14, 21], it is doubtful whether the apparently positive data of high scientific impact by itself with low autonomous significant science production and very high dependence of international collaboration would be able to give good perspectives for the country’s social and economic development.

| Country           | Rank | Articles  | Times cited | % Doc. cited | Citation impact | International collaborations | % International collaborations |
|-------------------|------|-----------|-------------|--------------|-----------------|------------------------------|--------------------------------|
| Brazil            | 1    | 539,049   | 4,997,160   | 69.5         | 9.3             | 158,083                      | 29.3                           |
| Mexico            | 2    | 175,970   | 1,886,483   | 69.9         | 10.7            | 74,953                       | 42.6                           |
| Argentina         | 3    | 133,349   | 1,611,771   | 73.4         | 12.1            | 56,759                       | 42.6                           |
| Chile             | 4    | 87,419    | 1,107,194   | 71.9         | 12.7            | 49,465                       | 56.6                           |
| Colombia          | 5    | 42,021    | 417,829     | 64.3         | 9.9             | 25,034                       | 59.6                           |
| Venezuela         | 6    | 21,667    | 239,514     | 68.2         | 11.1            | 11,064                       | 51.1                           |
| Cuba              | 7    | 14,331    | 145,440     | 71.1         | 10.2            | 9231                         | 64.4                           |
| Peru              | 8    | 12,892    | 181,816     | 66.6         | 14.1            | 10,246                       | 79.5                           |
| Uruguay           | 9    | 11,920    | 158,319     | 73.5         | 13.3            | 7997                         | 67.1                           |
| Costa Rica        | 10   | 7562      | 129,555     | 75.4         | 17.1            | 5679                         | 75.1                           |
| Ecuador           | 11   | 6972      | 85,375      | 68.6         | 12.3            | 5841                         | 83.8                           |
| Panama            | 12   | 4941      | 132,191     | 80.6         | 26.8            | 4262                         | 86.3                           |
| Total and average |      | 1,058,093 | 11,092,647  | 71.1         | 13.3            | 418,614                      | 61.5                           |

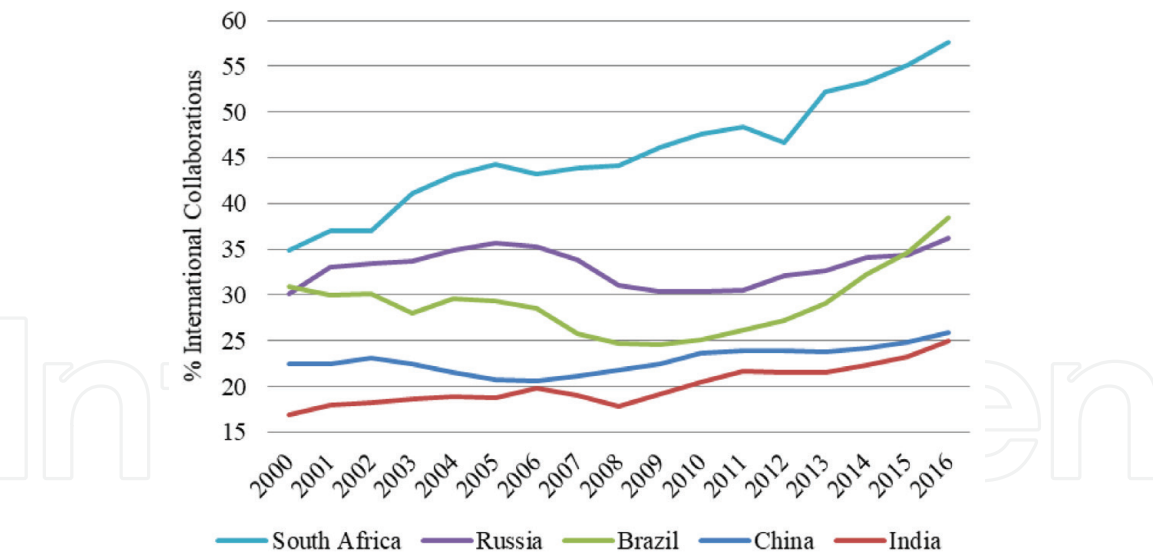
Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

**Table 4.**  
Productivity ranking of Latin American countries in 2000–2016.



**Figure 4.**  
International collaborations in scientific publications in Latin American countries in 2000–2016. Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

In the case of the BRICS countries, South Africa is the country with the highest international collaboration rate (48.0%) and the country with the highest impact (12.2) (Table 2). Figure 5 illustrates the recent evolution (2000–2016) of the international collaboration of the BRICS countries. With the exception of South Africa that exploits international collaboration at a level similar to the more developed countries, the other members of the group have much lower rates. Brazil, which has had an oscillating collaboration rate since the beginning of the period, has resumed a stronger growth from 2010 onwards, surpassing in 2015 the index of international cooperation shown by Russia.



**Figure 5.** International collaborations in scientific publications in WoS of the BRICS countries in 2000–2016. Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

| Country        |              | Total country articles | Collaboration with Brazil |                 | Collaboration on data from Brazil % |
|----------------|--------------|------------------------|---------------------------|-----------------|-------------------------------------|
|                |              |                        | Total articles            | Collaboration % |                                     |
| Latin American |              |                        |                           |                 |                                     |
| 1              | Mexico       | 175,970                | 5495                      | 3,1             | 1.0                                 |
| 2              | Argentina    | 133,349                | 9404                      | 7,1             | 1.7                                 |
| 3              | Chile        | 87,419                 | 5007                      | 5,7             | 0.9                                 |
| 4              | Colombia     | 42,021                 | 4954                      | 11,8            | 0.9                                 |
| 5              | Venezuela    | 11,920                 | 1722                      | 14,5            | 0.3                                 |
| 6              | Cuba         | 12,892                 | 1692                      | 13,1            | 0.3                                 |
| 7              | Peru         | 14,331                 | 1651                      | 11,5            | 0.3                                 |
| 8              | Uruguay      | 21,667                 | 1251                      | 5,8             | 0.2                                 |
| 9              | Costa Rica   | 6972                   | 1009                      | 14,5            | 0.2                                 |
| 10             | Ecuador      | 7562                   | 664                       | 8,8             | 0.1                                 |
| 11             | Panama       | 4941                   | 421                       | 8,5             | 0.1                                 |
| BRICS          |              |                        |                           |                 |                                     |
| 1              | China        | 2,275,635              | 5818                      | 0,3             | 1.1                                 |
| 2              | Russia       | 713,637                | 5401                      | 0,8             | 1.0                                 |
| 3              | India        | 510,662                | 4742                      | 0,9             | 0.9                                 |
| 4              | South Africa | 147,248                | 2737                      | 1,9             | 0.5                                 |
| Brazil         |              | 539,049                | —                         | —               | —                                   |

Source: ESI-InCites dataset updated 2017-04-15. Includes Web of Science content indexed through 2017-02-03.

**Table 5.** Scientific collaborations of Latin American and BRICS countries with Brazil in 2000–2016.

Based on the set of results shown for the Latin American and BRICS countries, we analyzed the scientific cooperation of these countries with Brazil. **Table 5** shows the total production data of the Latin American countries and the components of the BRICS group, the number of joint publications with Brazil, and the respective

percentage of collaboration of these countries with Brazil. The indices of collaboration in joint publications of Brazilian scientists with the Latin American or from BRICS countries are extremely low. Moreover, taking as an example the cooperation of the Latin American countries with Brazil shown in **Table 5**, it can be seen that the percentage of articles coming from this cooperation weighs much less on the total of Brazilian publications than on each of the partner countries, indicating that the rates of scientific cooperation among the countries of the region are very low when compared to the levels of international cooperation shown by these countries, as seen in **Table 5**. For Mexico's production, for example, this figure represents only 3.1% of its total scientific output and 14.5% for Costa Rica. For the estimation of this weight on Brazilian scientific production, the levels are even lower, varying from 0.1% (Panama and Costa Rica) to 1.7% with Argentina. A similar situation occurs when one compares the collaboration between scientists from BRICS countries and Brazil. That is, collaboration in the research projects of these countries, components of these two important trade blocs with Brazil, is practically nonexistent, suggesting that scientific and technological cooperation does not assume any significance in the context of these official partnerships. Nonetheless, such treaties emphasize that cooperation must include not only economic aspects but also scientific partnerships. Conversely, it has been observed for Latin American countries (data not shown) that intra-regional collaborations are much weaker than collaborations with developed countries. A similar situation was identified by Finardi [11] and Finardi and Buratti [12] for the BRICS case.

#### **4. Brazilian situation in the analyzed context**

In this article, special emphasis was given on the influence of international cooperation on the qualitative performance of scientific production. In the analysis presented here, which identifies in the low international scientific collaboration the unfavorable position of Brazil as concerned to the citations and impact of its publications, whether in the world context or in its position among the countries of the two economic blocs in which it participates, the MERCOSUL and BRICS. It is important, however, to point out that other factors, not discussed in this article, can influence the impact of scientific publications such as the size of the scientific community in each area of knowledge, the language, the maturity level of the areas in each country (or even the global world maturity of the same areas), and the degree of priority given by government agents to the technical and scientific development of certain areas with a view to explore comparative advantages as well as focusing the economic and social development of the countries.

As noted in an earlier study, the unbalanced and asymmetric international collaboration introduces profound distortions in the qualitative data of scientific production (citations, impact, world impact) of numerous countries and in the world, thus interfering in the expectations of scientific, technological, social, and economic development of the countries dependent on this type of international cooperation [14]. In this sense, in a recent article, Silva [22] deals with the relationship between productivity aspects and the quality of scientific production in the countries. The author makes severe criticism regarding comparisons of the scientific performance of Latin American countries. The author points out that it would not be appropriate to congratulate to some countries based on a simple analysis of these issues, since some countries have differentiated productivity in terms of their research and development priorities, with a high degree of self-financing, whereas the scientific production in other countries is highly dependent on the participation of international research groups and external financing. In our opinion, this



observation is aligned with a high degree of international collaboration. It remains to be seen whether in such situations there are the expected technical and socio-economic advances that this circumstance imposes on the dependent countries.

Concerning the specific case of Brazil, it is observed that the sharp growth of scientific production (see **Figure 1**) occurred in a short period of about four decades. This growth is clearly linked to the postgraduate programs since its installation in the late 1960s, resulting in the domestic training of thousands of teachers and doctors as well as research groups in universities and other centers, throughout the country. Although many researchers have enjoyed the possibility of partial or full training abroad since the 1970s, international collaboration in comparison with other countries has been less intensified and restricted to a few groups more oriented toward this form of production of new knowledge. This resulted in the small participation of Brazil in cooperative projects worldwide, a situation that affects, above all, the citations and, consequently, the impact of Brazilian science.

Nonetheless, it is also noted that, in several areas, the result of this domestic scientific development allowed Brazil to occupy a prominent position worldwide. Examples are the work in the fields of tropical medicine, dentistry, parasitology, agriculture, energy, biofuels, and more recently, in the studies on Zika virus and microcephaly. Also, as a result of the recognized qualification of human resources through the postgraduate courses and the consolidation of research groups in strategic areas, many technological sectors have had great development in recent years. Examples are deep water oil exploration, tropical agriculture, pulp and paper industry, aircraft production, offshore platforms, the metal-mechanic working industry, alcohol and biofuels, and banking automation, among others. The results of this development can be seen in the fact that Brazil occupies outstanding economic position (ninth) [23] in the ranking of the countries with the highest GDP in the world wise and the second (after the USA) highest per capita GDP (US \$ 15,359) among the most populous countries in the world.

Thus, the scientific and technological output of Brazil in several fields seems to confirm that the presence of internal training in human resources and infrastructure for research and development, even in the absence of strong international cooperation, can make it possible to attain significant scientific and socioeconomic advances in a short period of time. On the other hand, quantitatively unbalanced and technically asymmetric international cooperation, as is the case with about 70% of the countries analyzed recently [14], is certainly disastrous in enabling these countries to reach adequate levels of development to confront their social and economic challenges.

## 5. Conclusions

In this analysis, it can be observed that the impact of publications and, consequently, the greater visibility of science are directly influenced by the index of international collaboration between peers in the same area or related areas. This was evidenced in relation to the most productive countries and in the comparison of Brazil with Latin American countries and with the component countries of the BRICS group.

In the context of scientific production, international collaborations bring mutual benefits to partner countries, and in a broader and wider sense, they promote the social and economic prosperity of the groups involved. However, it should be noted that there should be an expected balance in these partnerships. As analyzed recently [14], the unbalanced and asymmetric scientific cooperation that occurs between many countries with very low scientific production but with

a high impact due to the participation in the publications of articles coming from international cooperation with developed countries masks the importance of the contribution of S&T to help these country's development. This situation, above all, eludes the prospects of obtaining technological, economic, and social advances from the nations dependent on such cooperation, to face their own challenges such as in food production, the provision of drinking water, food and health security, energy supply, public safety, and environmental protection, all of which are typical global problems requiring a scientific approach to their solutions and generation of sustainable development perspectives.

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