
Scientific Output Indicators and Scientific Collaboration Network Mapping in Brazil

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This is an investigation of Brazilian articles indexed by SCI between 2004 and 2006 with the purpose of understanding the scientific collaboration in the Brazilian community. The 49,046 articles that have been examined show that national scientific output increased every year during the period and that articles were published in a great number of journals, 15.7% of which were national publications. The most productive areas are Chemistry, Biology, Physics and Clinical and Experimental Medicine II. Authors from several institutions were identified, which indicates Brazil has yet to establish a consolidated pattern of publication, since several of the institutions contributed only one article (59.1%). Co-publication between individuals increased in the period, representing about 96% of national output. The mean number of authors per article is 6.3. Scientific output is concentrated in few institutions, mostly public universities located in specific regions. The mean number of institutions per article is 2.4, and looking into the most productive institutions, the practice of intra-institutional co-publication stood out. When relative collaboration indices and multivariate analysis were applied, regional groups proved to be formed. International co-publication decreased in percentage in the period, representing 30.3% of the total articles. The USA, France, the United Kingdom and Germany are the biggest partners in terms of articles; however, relative indices reveal the USA and Argentina are the main partners. Motivation for international collaboration seems to follow historical, linguistic and geographical proximity reasons.

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1. Introduction

The evaluation of scientific activity proves to be fundamental in countries where Science is mostly financed by public funds, as in the Brazilian case. Because funds are limited, there is supposedly competition among different sectors in society for the available governmental funds. In the last decade, Brazilian scientific output has grown yearly at a rate of about 8% and represents 45% of total Latin American output [1], which justifies the interest and effort in prospecting indicators that help S&T policies and strategies. Among countries in Latin America, Brazil is champion in growth, with a registered 8% addition to annual database [1]. It ranks 15th among nations that publish journals indexed by ISI [2] and 15th in productivity according to SCOPUS [3]. The country, however, still seems slow when it comes to the production of S&T indicators, despite questions aroused by the fast pace in amplifying scientific output.

Previous studies show growth of 40% in ISI indexed articles between 1981 and 1993 [4]. According to the author, these numbers are surprising since there was a cut in Science funds in Brazil between 1986 and 1992. However, from 1981 to 1993, while the number of articles published by a single author remained stable, the number of articles in national and international collaboration increased up to 250%. This outcome has led to the conclusion that the growth in ISI indexed Brazilian scientific output is a consequence of national and international scientific collaboration.

When international collaboration is analyzed, Glanzel, Leta and Thijs [1] have observed that in comparison to Argentina, Chile, Mexico and Venezuela, Brazil is the country with the lowest fraction of international collaboration between the years 1999 and 2003. As opposed to other Latin American countries, Brazilian publication in international collaboration did not increase in the period between 1991-1995. According to the authors, this outcome might be due to the fact that Brazilian researchers had incentive towards international collaboration during the 1980's, but not in the beginning of the 2000's.

Some of the data on collaboration confirm findings from previous studies [5]. In 2002, the authors had stated that the USA accounted for 40.5% of Brazilian publication in collaboration in the 1981-2000 period. The number of publications with at least one Latin American country showed increase and accounted for about 10% of those. Analyses show that collaboration among countries in the Southern Hemisphere is limited and that scientists in countries under development tend to collaborate intensively with peers from the Northern Hemisphere. In comparing Brazilian scientific output indexed by ISI between 1981 and 1990, an increase from 21.6% to 26.7% were found in publication in international collaboration. However, this percentage became stable after 1993 while the number of total Brazilian publications kept growing constantly, which led to the authors statement that international scientific collaboration in itself could not explain the growth in Brazilian scientific output indexed by ISI.

The previous paragraphs look back into some aspects and milestones of Science in Brazil and outline the Brazilian scientific output background until 2003. This paper has two objectives: first, expand the panorama of Brazilian science through an analysis of articles

indexed between the years 2004 to 2006, and then contribute towards the understanding of collaboration in Brazilian Science, by identifying factors related to scientific collaboration in Brazil, by analyzing the co-publication established between researchers affiliated to Brazilian institutions and those affiliated to institutions abroad. In the following sections we describe methodology and results. Final considerations close the text.

2. Methodology

This study comprises articles indexed by **Science Citation Index Expanded (SCI)** in 2004, 2005 and 2006, which contain at least one Brazilian address in the Author Address field. Data was collected on September 13, 19 and 20, 2007, using the words “Brasil” or “Brazil” in the search.

Geographical origin is based upon the address given by the author for the publication [6]. Therefore, “Brazilian” authors are considered those who have listed an address located in Brazil, independent from their place of birth or nationality. We have specifically chosen the years 2004, 2005 and 2006 in order to follow up on research carried out by Leta, Glänzel and Thijs [1] and by Packer and Meneghini [7], who studied the Brazilian scientific output indexed by ISI until 2003. We have chosen to analyze articles from journals for the purpose of this study because we consider them to be the main type of publication for consolidated scientific research outcome when compared to other types of publications indexed by ISI.

Multiple entries found in the Address (C1) field have undergone thorough standardization and this led to a 30% downsizing in institution names. After the clean up, data was grouped with the purpose of studying institutional collaboration, not collaboration that takes place within institutions. Therefore, entries for different departments within a specific university have been grouped under the institution to which they belong. For instance, the UFRGS Department of Biochemistry entries have been kept as an entry to the University (UFRGS), with the purpose of studying the inter-institutional collaboration. The same procedure was undertaken in case of companies: St Jud Med entries were grouped together, since the purpose was not to study whether or not the American St Jud was collaborating with the Brazilian branch.

Articles have been organized into different fields of publication according to the classification scheme for science fields and subfields defined by Glänzel and Schubert [8].

Bibexcel, 2007 Microsoft Excel version and Statistics Packet for Social Science (SPSS) version 14.0 comprise the software used in the analyses.

In order to make this study possible, we have assigned one article for each country listed in the Author Address field, following methodology applied in other bibliometric studies [9, 10, 7]. Because of this choice, total author, institution and country occurrence does not reflect the total number of articles that were published. When the co-authors from a given country were more than one, collaboration between the countries was attributed only once [11, 12]. For instance, an article published in co-authorship by two institutions in Brazil, one in France and two in the USA has been assigned as one article for Brazil, one for France and one for the USA.

The absolute numbers show the total articles written in co-publication disregarding the size of authors – measured by the total number of articles published which were involved in the collaboration. In order to estimate trend or intensity of co-publication, it was necessary to use relative indicators that would take the size of scientific output by author, institution or country into consideration. Luukkonen et al. [11] state that the total number of articles published in co-publication between two countries must be analyzed in relation to the total scientific output of each of the countries involved, when evaluating international scientific collaboration. If one of the countries is very productive and the other is not, collaboration between the two may not be very significant when compared to total productivity of the first, and on the other hand, it might be very significant if compared to the total published by the latter country.

The use of normalized relative indicators may reveal subjacent aspects that could not be seen by looking into raw data. To conduct the multivariate analysis we have used Salton' cosine as measure of similarity. In order to allow other analyses and interpretations, we have used the Collaboration Index, based on the formula created by Luukkonen, Persson and Sivertsen [10], which calculates the frequency that can be expected from a diagonal matrix value randomly distributed between all the cells. Index equal to 1 shows collaboration in accordance to expectation. Higher than 1 index shows higher than expected levels of collaboration. The statistical treatment has made the following assessment possible.

3. Results presentation and analysis

The data sample comprises 49,046 articles indexed by SCI between 2004 and 2006 containing at least one Brazilian address. There was a 5.9% increase in scientific output in 2005 in relation to the previous year (up to 16,260 articles in 2005 from 15,374 in 2004) and 6.8% in 2006 in comparison to 2005 (up to 17,412 articles from 16,260 in 2005).

Brazilian scientific output in the period was published by 4,650 different journals. The number of journals where it was published kept increasing from 2,860 in 2004, to 2,998 in 2005 and 3,213 in 2006, indicating the diversity of means used to publish findings. That obviously reflects on the wider number of journals indexed by ISI.

The number of articles that were published in Brazilian journals increased in the period under study. In 2004, 2,301 articles were published in national journals, representing 15% of the total. In 2005, this number rose to 2,600 and the percentage reached 16%. In 2006, the total number of articles went up to 2,786 and the percentage remained 16%. The total for the period under study is 7,687 Brazilian articles published in Brazilian journals, representing 15.7% of total Brazilian production. Among the 20 most recurrent journals in terms of article publication, we can find a majority of (15) national journals and Physics, one of the most representative areas in Brazilian scientific output, is most often the subject area.

The classification proposed by Glänzel and Schubert [8] was applied in the assessment of publication subject area. The result is presented as follows:

The subject area of Chemistry is one that stands out in the Brazilian scientific output, following a worldwide trend in scientific output [8]. Biology ranks second, showing yearly

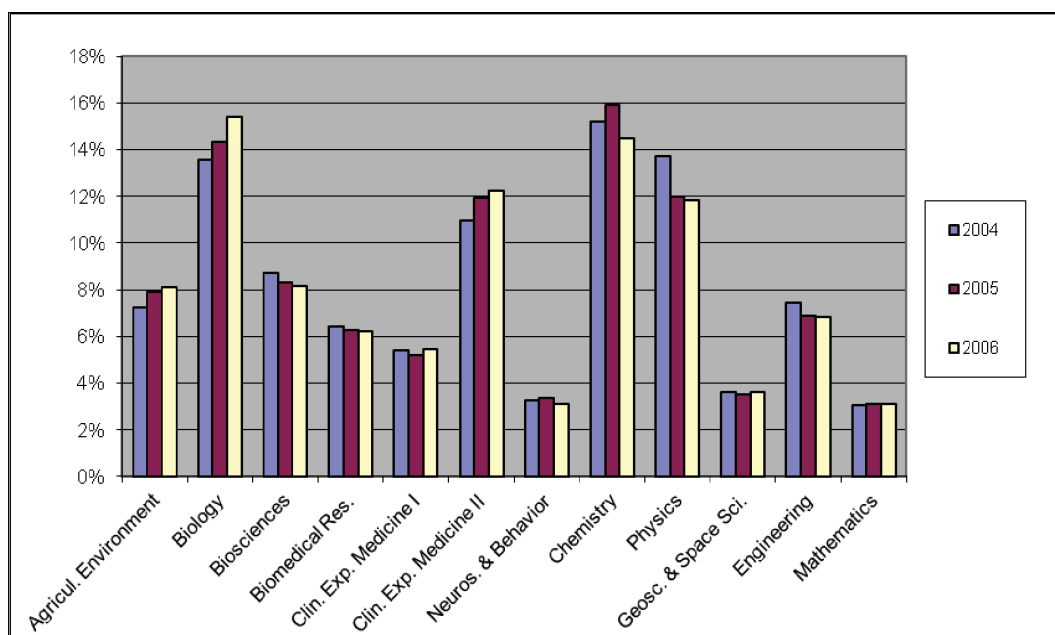


Figure 1
Brazilian Scientific output by subject areas, 2004-2006

increase; followed by Physics (which has shown a falling percentage year by year) and by Experimental Clinical Medicine II (with an yearly increase).

In order to interpret collaboration and co-publication appropriately they must be studied in their specificities and according to each level of aggregation. We understand that collaboration between individuals permeates collaboration between institutions and countries and therefore we have tried to evaluate each of these collaboration forms using different approaches and analyses.

The mean value of authors per article increased every year, starting at 5.9 authors per article in 2004, going up to 6.4 in 2005 and 6.5 in 2006, which gives us an average 6.3 authors per article for the period under study. Brazil follows a worldwide trend of increasing number of co-authors per article, from 1.83 in 1955 to 3.89 in 1998, according to SCI [9], and 4.16 authors per article in 2000 [13]. Although Brazil follows a worldwide pattern, the results we have found show that Brazil has a higher average (6.3 authors per article) when compared to other countries. The same study by Glänzel and Schubert [13] shows that a single author had signed 10.7% of the articles. In comparison, Brazil presents only 3.9% of its scientific output published under only one name in the three years our study comprises. That shows co-publication is an intensified practice in the country and that Brazilian scientific community can be found in ISI databanks, publishing mostly articles written in collaboration on an individual level.

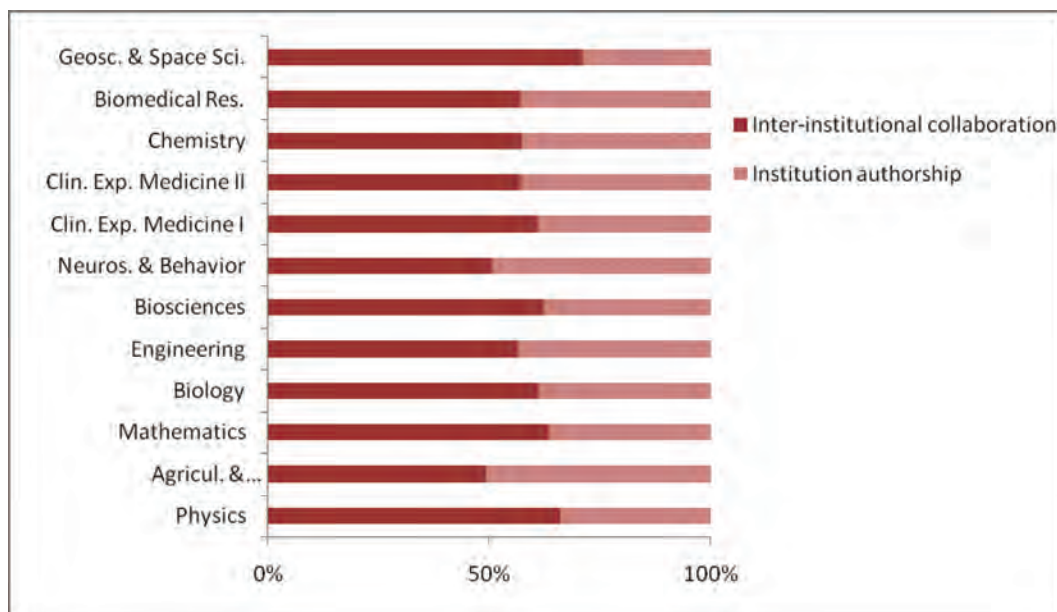


Figure 2
Inter-institutional co-publication by subject areas, 2004-2006

We have made some analyses with the purpose of verifying collaboration between different institutions (national and international). The average number of institutions bound to each article is 2.4. The graph below shows percentage of articles published by a single institution and those published in collaboration between different institutions:

The following Table 1 allows us to see the group of 16 most productive Brazilian institutions. They have been ranked according to total articles indexed in the period and respective percentages.

Public research institutions and universities lead the ranking of most productive institutions and there is a distinctive difference between the first ranking institutions. Brazilian Science is indeed concentrated in the public sector due to the fact that 70% of the Brazilian scientists work for public universities and research institutions [14].

The high ranking of institutions from São Paulo can be explained by the investment in Science in the State of São Paulo. According to Zorzetto et al. [15], the public and private sectors in the State funded 4.5 billion dollars in research and development activities in the year 2000, almost 40% of the total investment in the country. The Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) invested 40 million dollars per year in research in the medical area between 1998 and 2000, which corresponds to 35% of investment made by the six public agencies in the area. The current investment reinforces other factors that contribute towards this outcome, such as the process of Science institutionalization in the State [16].

Table 1
Number of articles from the most productive institutions, 2004-2006

Institution	N. articles	%
Universidade de São Paulo	12,384	10.8
Universidade Estadual de Campinas	5,010	4.4
Universidade Federal do Rio de Janeiro	4,336	3.8
Universidade Estadual Paulista Julio de Mesquita Filho	3,754	3.3
Universidade Federal do Rio Grande do Sul	2,916	2.5
Universidade Federal de Minas Gerais	2,541	2.2
UNIFESP	1,821	1.6
FIOCRUZ	1,546	1.3
Universidade Federal de Santa Catarina	1,394	1.2
Universidade Federal de São Carlos	1,440	1.3
Universidade Federal do Paraná	1,272	1.1
EMBRAPA	1,382	1.2
Universidade Federal de Pernambuco	1,222	1.1
Universidade Federal de Viçosa	1,048	0.9
Universidade de Brasília	1,132	1.0
Universidade Federal do Ceará	1,012	0.9

In order to look into any behavioral patterns that might arise in terms of institutions, we move on to multivariate analyses based upon the descriptive analyses of the institutions authors are affiliated to. Due to the great number of institutions comprised by the study, the multivariate analyses were conducted with the group of 16 most productive institutions alone. MDS, factor and cluster analysis were used in order to check for collaboration patterns.

The co-author matrix was generated in order to allow co-authorship analysis among the institutions. Data show the predominance of intra-institutional collaboration, that is to say collaboration within the same institution. When the intra-institutional collaboration percentage was calculated in relation to total collaboration by a single institution with the other 15 institutions in the sample group, a percentage around 40% was found, varying from a minimum 10.4%, registered by UFSCAR, to a maximum 64.9% presented by UFRGS. Intra-institutional co-authorship means collaboration between different institutes, faculties, departments and/or postgraduate programs within the same institution

The formula written by Luukkonen, Persson and Sivertsen [10], which has been described in the Methodology section of the paper, was applied to the institutional co-authorship frequency matrix presented. The result is posted in Table 2.

Table 2
Institutional index of co-publications, 2004-2006

	EMBRAPA	FIOCRUZ	UNB	UNICAMP	UNESP	UFCE	UFMG	UFPR	UFPE	UFRJ	UFRGS	UFSC	UFSCAR	UNIFESP	UFV	USP
EMBRAPA	4.4	0.2	4.7	0.4	0.8	0.8	0.9	1.0	0.9	0.8	1.0	0.5	1.0	0.1	4.7	0.7
FIOCRUZ	0.2	6.8	0.3	0.1	0.2	0.3	2.7	0.1	1.2	3.4	0.2	0.3	0.1	0.4	0.3	0.3
UNB	4.7	0.3	15.5	0.5	0.5	0.5	0.7	0.2	1.1	0.4	0.5	0.4	1.0	0.3	0.4	0.7
UNICAMP	0.4	0.1	0.5	3.8	1.0	0.9	0.3	0.8	0.6	0.4	0.4	0.4	0.9	0.6	0.2	1.0
UNESP	0.8	0.2	0.5	1.0	3.2	0.5	0.3	0.4	0.2	0.2	0.2	0.4	2.4	0.5	0.6	1.2
UFCE	0.8	0.3	0.5	0.9	0.5	16.2	0.6	0.5	2.8	0.5	0.3	0.6	0.8	0.7	0.5	0.5
UFMG	0.9	2.7	0.7	0.3	0.3	0.6	8.2	0.4	0.4	0.5	0.2	0.4	0.3	0.4	1.7	0.4
UFPR	1.0	0.1	0.2	0.8	0.4	0.5	0.4	12.5	0.7	0.6	0.6	3.0	1.4	0.7	0.2	0.7
UFPE	0.9	1.2	1.1	0.6	0.2	2.8	0.4	0.7	20.8	0.3	0.5	0.5	0.4	0.2	0.3	0.5
UFRJ	0.8	3.4	0.4	0.4	0.2	0.5	0.5	0.6	0.3	5.9	0.4	0.8	0.2	0.6	0.2	0.4
UFRGS	1.0	0.2	0.5	0.4	0.2	0.3	0.2	0.6	0.5	0.4	11.7	1.5	0.1	0.2	0.1	0.4
UFSC	0.5	0.3	0.4	0.4	0.4	0.6	0.4	3.0	0.5	0.8	1.5	15.0	1.1	0.2	0.1	0.6
UFSCAR	1.0	0.1	1.0	0.9	2.4	0.8	0.3	1.4	0.4	0.2	0.1	1.1	3.3	0.2	0.2	1.2
UNIFESP	0.1	0.4	0.3	0.6	0.5	0.7	0.4	0.7	0.2	0.6	0.2	0.2	0.2	7.0	0.0	1.1
UFV	4.7	0.3	0.4	0.2	0.6	0.5	1.7	0.2	0.3	0.2	0.1	0.1	0.2	0.0	18.8	0.3
USP	0.7	0.3	0.7	1.0	1.2	0.5	0.4	0.7	0.5	0.4	0.4	0.6	1.2	1.1	0.3	1.7
Total ≥ 1	6	4	4	3	4	2	3	4	4	2	3	4	7	2	3	5

EMBRAPA, major Brazilian institution in the agricultural and livestock area shows an intra-institutional collaboration index 4.4 times higher than expected and an index close to 1 in relation to other institutions, which points to a collaboration profile with a wide range of partners, probably due to the fact that the institution has 41 stations in different cities in the country. Co-publications with FIOCRUZ and UNIFESP were an exception, registering a lower index when compared to the others (0.2 e 0.1).

FIOCRUZ, major Brazilian research institution in the Biological Science area, has higher than expected frequency of collaboration with UFPE (1.2), UFMG (2.7), UFRJ (3.4) and within the institution itself (6.8). With the other institutions the frequency reported is lower than expected, indicating low level of collaboration in relation to the sample group. A possible explanation for co-publications with UFMG would be the recognized quality of its scientific output in the Biology and Health areas. However, another factor that makes this partnership between FIOCRUZ and UFMG researchers favorable is the fact that there is a FIOCRUZ unit near Belo Horizonte.

UnB has a high collaboration index with EMBRAPA (4.7 - possibly motivated by the fact that the company is located in the city of Brasília), within the institution itself (15.5) and a reasonable index in relation to the other institutions in the sample.

UNICAMP has a collaboration frequency index lower than expected, except for the intra-institutional collaboration, which is 3.8 times higher than expected, and the collaboration with UFCE and UFSCAR, which is almost what was expected (0.9) and with UNESP (1).

Another institution from São Paulo, UNESP, shows the second lowest intra-institutional collaboration index in the sample group (3.2). The collaboration index with UNICAMP is exactly what was expected (1), with USP is a little higher than expected (1.2) and a little higher with another institution from São Paulo, UFSCAR (2.4). Again we can see that the geographical factor plays an important role.

The geographical factor seems to predominate partner choices for other institutions such as UFCE, UFMG, UFPR, UFPE and UFSC. UFCE shows higher than expected rate within the institution (16.2) and with UFPE (2.8), also located in the Northeast of the country. Similar behavior can be seen in UFMG, which in general shows lower than 0.5 rates, except with FIOCRUZ (2.7) and UFV (1.7), located in the same State, and intra-institutional collaboration is 8.2 times higher than expected. UFPR has higher rates of collaboration with EMBRAPA (1.0), UFSCAR (1.4) and UFSC (3.0), the two latter located in neighboring States. Geographical proximity can be slightly noticed in the choice of partners by UFPE: FIOCRUZ (1.2), UnB (1.1) and UFCE (2.8). Only UFCE is located in the Northeast region. The institution has the highest index of intra-institutional collaboration in the sample group – 20.8. UFSC concentrates partners in the South of the country: UFPR (3.0), UFRGS (1.5) and UFSCAR (1.1), this last one is located in the south of São Paulo.

UFRJ shows a higher than expected frequency in collaboration with an institution from Rio de Janeiro FIOCRUZ (3.4), and has an intra-institutional collaboration rate 5.9 times higher than expected. UFRGS, registers the highest percentage of intra-institutional collaboration in the sample (64.9%). However, it does not have the highest index (11.7). It seems

to collaborate little with the sample group and EMBRAPA and UFSC are the only partners with an index equal to or higher than expected (1.0 and 1.5). UFSCAR has a collaboration index equal to or higher than expected with 7 institutions, with a profile that tends to collaborate with a variety of institutions in the sample group. It is also the institution that shows the lowest percentage of intra-institutional collaboration.

UNIFESP does not seem to collaborate much with the other institutions in the sample, except for USP with an index a little higher than expected (1.1). Intra-institutional collaboration is 7 times higher than expected. USP registers the lowest intra-institutional collaboration index in the sample: 1.7 times higher than the frequency expected and an index equal or higher than 1 in relation to four partners, all in São Paulo: UNICAMP (1.0), UNESP (1.2), UNIFESP (1.1) and UFSCAR (1.2).

If we take a look at the bottom line in Table 2, we can see that there are institutions with only two partners that reach index 1 or higher, meaning that collaboration is concentrated within the institutions and a few other specific partners, rather than randomly distributed in the sample group of 16 institutions that were studied. Data reveal that the universities in São Paulo do not only stand out in terms of productivity when compared to the rest of the country but they also have their own collaboration network. Universities in São Paulo are surprisingly dynamic and there are strong historical reasons that explain that fact [16].

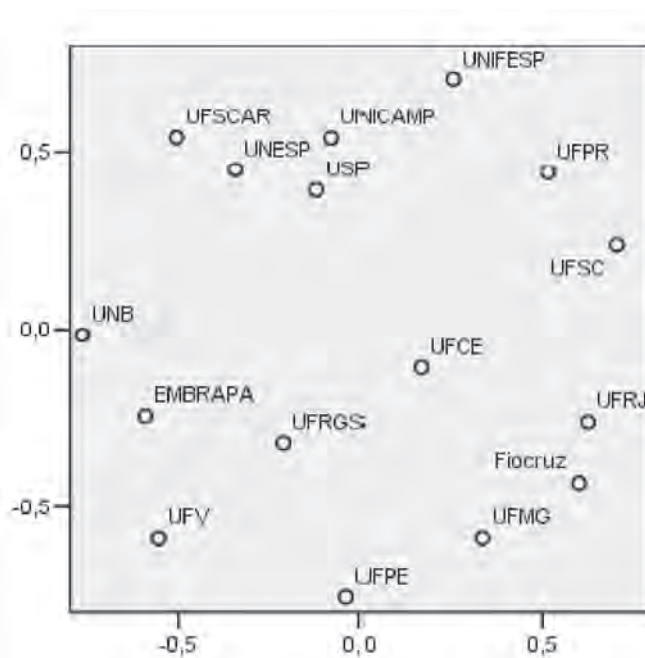


Figure 3

MDS Map of the 16 institutions, 2004-2006 (Stress 0.09402)

Multivariate analysis based upon the co-publication matrix normalized by the Salton's Cosine was carried out with the purpose of looking into the relationship between the 16 most productive Brazilian institutions. MDS Proxscal analysis, indicated for similar and dissimilar data [17] was used and we have chosen the Spline transformation model because data was being processed in SPSS [18] version 14.0. The result is shown in the map that is presented below.

The map shows that institutions tend to cluster for geographical reasons, given the position of UFRJ, Fiocruz and UFMG on the bottom right corner, UFPR and UFSC on the top right corner and the universities from São Paulo on the top of the map. Cluster by subject area can be seen in the EMBRAPA, UNB and UFV positions. However, it is important to keep in mind that the position of the institutions on the map is not fixed, but rather partly determined by the group of institutions chosen for the sample analysis.

Factor and cluster analyses reinforce the MDS solution presented. The institutions in São Paulo UNICAMP, UNESP, UFSCAR and USP, showing a trend towards geographic clustering, explain the first component. The subject area group explains the second component, comprised by EMBRAPA, UFV and UnB that also explains the fifth factor. The third component is created by FIOCRUZ, UFRJ and UFMG. UFCE and UFPE explain the fourth factor, which is also explained by UFPR and UFSC oppositely charged. Both the second and fourth factor point to geographic clustering. UNIFESP is responsible for the explanation of the sixth factor while UFRGS explains the seventh factor.

Other authors have reported the institutional bias of Brazilian research. The existence of a cluster between São Paulo and Paraná state universities was observed in articles published between 1986 and 2006 in the area of Bioprospecting [19]. The same study showed EMBRAPA and the federal universities of Lavras and Viçosa to appear isolated in the cluster analysis.

The descriptive analysis, co-publication index, MDS, factor and cluster analysis allow us to make a few considerations. The 16 institutions under study have, in general, high indices of intra-institutional co-publication and lower indices of co-publication with each other. This leads us to think that co-publication between institutions does not yet fully take place between the institutions in the sample group.

There seems to be a preference cluster, following a geographic structure in terms of co-publication between institutions: institutions in São Paulo create a network, except for UNIFESP that can be seen in isolation. In the South, UFRGS is also isolated, while UFSC and UFPR create a collaborative group with UFSCAR (located in a neighboring state). UFMG, UFRJ and FIOCRUZ form another relationship with neighboring states. UFCE and UFPE also seem to concentrate in the Northeast region. EMBRAPA shows collaborative behavior, probably because of its stations in several different Brazilian cities.

Now, international co-publication is a phenomenon that can be seen in 30.3% of Brazilian articles. Most of the articles (75.3%) are written by authors from two countries; 15.4% of the articles in the sample show three countries in co-publication; and 9.2%, four or more countries involved, considering one of them to be necessarily Brazil. These results seem to

indicate that Brazil is gradually following a worldwide trend of increased number of partners in international collaboration.

The international collaboration growth in the 1980's and subsequent downsizing during the 1990's was caused by changes in incentive policies towards collaboration with foreign researchers. In 1993 international collaboration represented 26.7% of Brazilian scientific output [5]. The study of scientific output for the 50 most productive countries in ISI in 1995/1996 shows that 41.7% of the articles published by Brazil were written with international partners [20].

When looking into the findings in this study in combination with those presented by Glänzel [20] and Leta and Chaimovich [5], we can see that the trajectory of Brazilian international collaboration oscillates from 26.7% of the articles in 1993 to a peak of 41.7% in 1995/1996 and subsequent drop to 30.3% in 2004/2006.

Although there has been a trend of downfall, international co-publication in Brazil still shows higher percentages when compared to global scientific output. Studies reveal that 23.3% of scientific output indexed by SCI in 2005 was published as international co-publications [21]. Luukkonen, Persson and Sivertsen [10] state that countries with less developed scientific infra-structure tend to have higher rates of international collaboration, which is an explanation that could justify the 30.3% of international articles found in the Brazilian scientific output in the 2004-2006 period.

The graph below shows international collaboration by subject area. A significant percentage difference between the areas in terms of international collaboration was found.

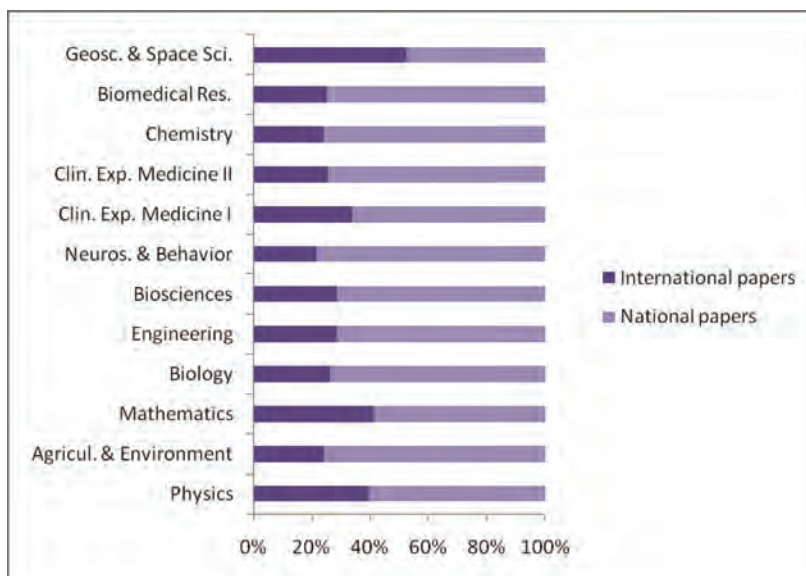


Figure 4

International co-publications by subject areas, 2004-2006

The area that shows the highest percentage is Geosciences, with more than 50% of the articles having been written in international collaboration. This area had shown 48.7% of articles in international collaboration in the period 1981-1993 [22]. Right below it we can find Mathematics and Physics, both around 40%. When comparing the findings to those presented by Leta and Meis [22], both areas have had an increase in relation to the 1981-1993 period, when the percentage of collaboration was 38.2 and 34%, respectively. Other areas have shown average or little below average percentages, with about 30% of international collaboration.

The USA still stands out as the most significant partner country for Brazil and participates in 22.7% of co-publications, followed by France, with a percentage 2.7 times smaller (8.2%), the United Kingdom and Germany (7.3%), and Italy increasing to almost half the percentage of the other European countries (4.3%).

Leta and Chaimovich [5] findings showed that between 1981 and 1999, the Middle East and Africa comprised 1.5% of Brazilian collaboration, and Latin America represented about 10% of the publications and the USA co-authored 40.5% of Brazilian international articles. We can see that there has been a percentage reduction for the USA – from 40.5% to 22.5% - in international Brazilian co-publications when comparing the results found by the authors in the 1981-1999 period and the present 2004-2006 study. Apparently Brazil has tried to diversify partners and to intensify collaboration with other partners, thus reducing its scientific dependency on the USA.

In order to investigate the existence of a co-publication network based on language and geographical proximity between countries, we have used the nonparametric One Sample Kolmogorov Smirnov test. The null hypothesis is equal distribution of articles in co-publication among the 21 countries presented in Table 6 (except for the “other countries” entry). The test result rejected the null hypothesis of equal distribution (.000, and therefore, $p > 0.05$), confirming that the co-publication distribution among partner countries for Brazil does not take place evenly and that there is a tendency towards certain countries. The fact that the USA is the main Brazilian partner by far when compared to other countries might have altered the analysis. In order to ensure the rejection of H_0 , we have excluded the USA from the sample and again the result ($p = .003$) rejected the hypothesis of equal distribution, even among countries that had a smaller number of articles written in collaboration with Brazil.

The co-publication frequency between Brazil and other countries is a useful absolute indicator to measure scientific performance. However, the use of relative indicators to evaluate international collaboration might show other sides of the scenario, since these indicators use size of the countries, measured by total country output. In order to make other analyses and interpretations possible, we have applied the formula created by Luukkonen, Persson and Sivertsen [10], which has been thoroughly outlined in the Methodology section of the study.

The index shows that co-publication number is higher than expected especially in case of countries without scientific tradition or recently consolidated tradition in the Central and South American continent: 4.1 times higher in the case of Argentina; 4.8 times higher

for Bolivia; 3 times higher for Chile; 6.1 times higher for Colombia; 6.8 times higher for Suriname; 4.3 times higher for Costa Rica; 4 times higher for French Guyana; 7.6 times higher for the Dominican Republic; 10.6 times higher for Ecuador; 2.8 times higher for Guatemala; 1.7 times higher for Haiti; 4.8 times higher for Honduras; 3.7 times higher for Nicaragua; 6 times higher for Panama; 17.8 times higher for Paraguay; 6.2 times higher for Peru; 1.4 times higher for Mexico; 8.7 times higher for Uruguay and 3 times higher for Venezuela. In the case of Portugal, a country with which Brazil has kept a relationship of political, economical and cultural dependency for several decades, the collaboration was 2.7 times higher than expected.

There seems to be consensus in the literature that the main Brazilian partners are still the USA and Western Europe and that collaboration within South and Latin America is still modest, where only Argentina, Chile, Mexico and Colombia stand out. However, when taking into consideration the size of Brazilian and neighboring countries' scientific output, we can see that collaboration between them happens more often than expected.

Complementarily, we have used Salton's Cosine to measure the strength of Brazilian collaboration with other countries. Among partner countries that showed Salton's Cosine number higher than 1 we can find several Latin American countries: Venezuela (1.2), Colombia (2.1), Ecuador (1.7), Peru (1.3), Chile (1.9), Argentina (3.4), Uruguay (2.1) and Paraguay (1.2). The USA (2.7), Canada (1.3), Mexico (1.3) and Cuba (1.6) comprise a group of partners in America. In Europe, Brazil has strong collaborative ties with Germany (1.8),



Figure 5

International co-publication 2004-2006 (Salton's Cosine ≥ 1)

France (2.3), Italy (1.4), Spain (1.4), Holland (1), Portugal (2.4) and the United Kingdom (1.8). We followed the same criteria applied by Glänzel, Leta and Thijs (2006) to classify the strength of the relationships: strong relationship (Salton's Cosine number ≥ 2.5), medium strength relationship (Salton's Cosine number ≥ 1 and < 2.5) and weak relationship (Salton's Cosine number smaller than 1). The map below shows the strong and medium strength relationships:

We can make a few considerations when comparing the results found in this study to those reported in the study by Glänzel, Leta and Thijs [1] for the 1999-2003 period. Argentina and the USA are still the most important partners for Brazil; however, new partners have now become part of the group of countries with which Brazil has what we consider to be medium strength relationships, such as Paraguay and Holland.

The important relationship (measured by a Salton's number higher than 1) between Brazil and the USA, and Brazil and Argentina had already been reported in the study by Glänzel and Schubert [13], based upon the world scientific output indexed by ISI in 2000. In 1990 besides the USA, Brazil had important ties with France and the United Kingdom. In 1980, the USA was the only country with which Brazil kept a co-publication rate higher than 1%. Based upon the comparison between previous studies and our findings, we can state that the diversity of countries with which Brazil collaborates has increased in the last 3 decades. Another index, the Probabilistic Affinity Index (PAI), has also shown an intense relationship between Brazil and the USA in ISI between 1986 and 1996 [12].

We can make a few considerations when looking into the results of the indices of co-publication and of the Salton's Cosine applied to international co-publication. Apparently the combination of historical factors, geographic and linguistic proximity can explain the close relationship between Brazil and some of its partners in the publication of articles. Historical motivations can explain the relationship with Italy, country that showed a Salton's Cosine number of 1.4, and with Germany with a 1.8 Cosine. Despite Germany's scientific tradition, the historical relationship created by the immigration to Brazil might constitute the main reason for the collaboration with this country and also with Italy, especially in terms of the language that is taught by the family through generations. Holland is another country that had a settlement in the Northeast of Brazil for several years and shows Salton's Cosine of 1. However, further analysis and the investigation of bilateral agreements in existence are needed in order to make conclusions on the matter. The historical and linguistic relationship with Portugal, country with a co-publication index of 2.7 and Salton's cosine of 2.4 is also evident.

The chart above shows the mean number of authors, institutions and countries involved in each article. We can see that the mean of countries per article remains constant during the period (2.6), and the mean number of institutions increases 0.1 between 2004 and 2005. The mean number of authors, however, showed an annual increase: starting at 5.9 authors per article in 2004 with an increase to 6.4 in 2005 and 6.5 in 2006. In relation to the percentage of co-publication in Brazilian scientific output, we can see that international co-publications decreased in the period, starting at 30.8% of the articles in 2004 and slightly going down to 29.9% in 2006. However, co-publication between Brazilian institutions that

Chart 6. Summary of main results

		2004	2005	2006
Mean per article	Authors	5.9	6.4	6.5
	Institutions	2.3	2.4	2.4
	Countries	2.6	2.6	2.6
Articles	International co-publication	30.8%	30.1%	29.9%
	Co-publication between Brazilian institutions	41.4%	43.4%	44.3%
	Co-publication between individuals	95.7%	95.8%	96.7%

represented 41.4% of the articles in 2004, increased to 44.3% in 2006. Co-publications on an individual level increased 1% during the period.

These findings show the existence of a difference in the pattern of article publication that varies according to the subject area in Brazilian scientific output. In order to further study the results, we have tried to show how collaboration in different areas takes place in detail. The table and graphs below show that Brazilian researchers publish in co-authorship, but it seems this practice is much more recurrent on individual levels than it is between different universities and countries:

Table 3
Mean numbers of authors, institutions and countries per subject areas, 2004-2006

	Means per article		
	Authors	Institutions	Countries
Geosciences	8.8	3.4	2
Bio-medical Research	5.6	2	1.3
Chemistry	4.6	1.9	1.3
Clinical and Experimental Medicine I	7	2.7	1.7
Clinical and Experimental Medicine II	5.6	2.2	1.4
Neuroscience	5.3	1.9	1.3
Bio-science	5.5	2.1	1.4
Engineering	4.1	1.9	1.4
Biology	4.7	2.1	1.4
Mathematics	2.5	1.9	1.5
Agricultural and Environmental	4.6	2	1.3
Physics	13.3	3.6	1.9
General	6.3	2.4	1.5

The results in Table 3 show differences between areas, mainly in the mean number of authors per article. It can be assumed that these numerical differences reflect real differences in the way scientific research is carried out in each of the subject areas. Research productivity is also a consequence of the different behaviors. A researcher that works alone, or in small groups, probably publishes fewer articles than those who work in a large laboratory or multinational project.

4. Final Considerations

Analysis of the 49,046 Brazilian articles indexed by ISI in the 2004-2006 period showed that the number of articles increased about 6.3% every year and they had been published by 4,650 different journals, 24 of which were Brazilian. From the total, 7,687 had been published in Brazilian journals, which represents 15.7% of total national output. These results indicate the diversity of means used in the publication of the research results.

The main areas were Chemistry, Biology, Physics and Clinical and Experimental Medicine II. However, Agriculture, Biology, Clinical and Experimental Medicine I and II, Geosciences and Spatial Science, Engineering and Mathematics showed increase in the period. Chemistry had an increased number of articles, but percentage decrease in relation to total Brazilian scientific output.

When analyzing the co-publication between individuals it can be noted that Brazil follows a worldwide trend of increased number of mean authors per article. However, the national mean (6.3 authors per article) is a lot higher than the worldwide mean for the year 2000 (4.16 according to data collected by Glänzel and Schubert [13]). The fact that only 3.9% of the articles were written by a single author reinforces the idea that Brazil can be found in ISI database mostly in articles written between individuals in co-publication.

The increase in number of co-authors per article that can be found in national articles indexed by ISI can be interpreted as a result of adherence by the Brazilian scientific community to the international movement towards amplification of scientific collaboration. However, there might be another way to look into these results. It is widely known that agencies such as CAPES and CNPq that support Brazilian research require researchers to publish their results. Thus, including peer names could be an attempt to “share” articles so as to increase the number of publications per researcher. This could be the reason for the large number of researchers per group. However, quantitative data are not enough to make any such assumptions.

Co-publication between institutions has also been assessed. The mean number of institutions per article is 2.4 and it falls to 1.6 when considering national institutions alone. Geosciences and Spatial Science areas show higher percentage of co-publication between institutions, followed by Physics and Mathematics. Analysis on the institutions shows that Brazilian scientific output is concentrated on a few institutions, most of which public university institutions. Regional concentration can also be seen, especially in the Central-West and South regions. Scientific output from private companies is not significant yet. USP is the most productive institution

Analysis of the 16 most productive institutions in the period showed that co-publication within institutions varied from 10.4%, UFSCAR rating, to a maximum of 64.9%, by UFRGS. We have applied a co-publication index in order to relativize co-publication according to expectation and USP showed the lowest rate of intra-institutional collaboration. MDS analysis of grouping and factor showed the existence of regionally formed groups.

The percentage of articles written in international co-publication dropped during the period under study but a significant percentage difference was found in different subject areas. The area that showed the highest percentage was Geosciences, with more than 50% of the articles having been written in international collaboration, followed by Mathematics and Physics, both with about 40%.

In terms of partner countries, the USA was found in 22.7% of co-publications, followed by France, the United Kingdom and Germany, Italy, Canada, Spain and Argentina. We have used the international co-publication rate to relativize the rate we found and that which was expected through the total output of the countries and the co-publication found is especially higher than expected for countries in Central and South America. When applying Salton's Cosine the data showed that the main Brazilian partners are Argentina and the USA. The relationship established with partners seems to follow historical, linguistic and geographical proximity motivations. Analysis of countries in co-publication added to the statistical test results that proved that the distribution of co-publications between partner countries does not take place evenly, leads us to accept the hypothesis of co-publication networks related to language and geographical proximity between institutions and countries.

Although we can see a drop in the percentage of articles in international collaboration in the period, co-publication is a constant practice in the scientific community, especially on an individual level. The fact that this type of collaboration has grown during the period under study and that it has higher percentages than the worldwide rate makes the idea that growth in the number of Brazilian articles indexed by ISI is related to the growth in the number of articles published in co-authorship acceptable. However, it is considered important to follow up on the research with a bigger sample of data in order to insure adequate statistical testing.

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