New Approach to the Visualization of International Scientific Collaboration

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Original Article

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Abstract In this study, visual representations are created in order to analyze different aspects of scientific collaboration at the international level. The main objective is to identify the international facet of research by following the flow of knowledge as expressed by the number of scientific publications, and then establishes the main geographical axes of output, showing the interrelationships of the domain, the intensity of these relations, and how the different types of collaboration are reflected in terms of visibility. Thus, the methodology has a twofold application, allowing us to detect significant differences that help characterize patterns of behaviour of a geographical system of output, along with the generation of representations that serve as interfaces for domain analysis and information retrieval.
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Introduction

Evaluating and reporting the results of scientific activity is a difficult undertaking, as the products involved have a dual nature, being tangible in certain ways yet intangible in others. The study of international collaboration may be quantified through collaborative projects, publications in common, informal contacts, the interchange of researchers or fellows among different countries, and participation in congresses.[1] Whatever the unit of analysis chosen for the study of international collaboration, bibliometric studies alone cannot do full justice to the dynamics of the process[2] because not all these activities lead to papers or reports published by the collaborating parties. Even so, studies based on the authorship of scientific publications afford a good estimate of this information.[3]

Scientific activity takes place within a complex, multidimensional network of interrelated activities and factors. The reticular and complex nature of the system of scientific communications through which knowledge is generated is not fixed machinery, but rather the result of a continuous process in which media and mechanisms of an increasingly complex nature participate, deriving from the interaction between the system and it's setting.[4] Collaboration in the scientific realm is a reflection of the interaction of individual networks which, in turn, reflect institutional and global networks.[5,6] These networks are conditioned by social and cultural factors as well as scientific ones, all well documented in the specialized literature.[7–10] Depending on the level of aggregation under analysis and the techniques used, these conditioning factors can be explored in greater detail. Such a focus affords an opportunity to elaborate indicators that reveal the organization of the patterns of communication, and the possibility of generating visual representations of the system in which they are

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rooted. Moreover, we may determine the volume and impact of each country's scientific output, the breadth and scope of its networks of collaboration, and, consequently, the national capacity for receiving or transmitting the flow of knowledge.

Newman defines a social network as a set of persons, groups or entities that have interconnections among themselves. In social network theory, these persons, groups or entities are known as actors, and the interconnections are their relations. Both the actors and the relations can be defined in different manners depending on the study at hand, at the macro, meso or micro level.[11] The relations that may be subjected to analysis and representation within the scientific community are very diverse. In the present study, we focus on the relationships deriving from scientific collaboration as seen in the publications signed by two or more countries, and more specifically, in the visual representation of the impact of research according to the type of collaboration established and the main geographical axes that appear.

Previous Research on Scientific Collaboration

Despite the fact that science sociologists carried out the first studies of scientific collaboration in the 1960s, the use of co-authorship data to examine international scientific collaborative activities is a more recent phenomenon. It was not till the 1990s when they became abundant, and the use of these data and the methodologies proposed became diverse.[12]

In the late 1950s, Smith was one of the first to observe an increase in works with multiple authorship, and to suggest that this characteristic could be used to represent collaboration among research groups.[13] At present, the increase in scientific collaboration is well documented at all levels of aggregation and evidences the growing importance of multilateralism and internationalization in scientific production.[14,15] It seems evident that the greatest potential of international collaboration resides in its capacity to solve complex problems and promote various political, economic and social agendas, such as democracy, sustainable development, and cultural understanding and integration.[16] Yet, we still have an incomplete understanding of the dynamics of collaboration at the global level, and of how it differs from nationally-based or institutionally-based research, or local collaborative efforts.[17]

During the late 1970s, the study of 'invisible schools' by Price and Beaver appears,[18] leading to an abundance of literature about social networks among scientists and patterns of communication in different fields of knowledge; Friedkin,[19] in 1978, offers an excellent review thereof. During the 1990s, is reinforced and contrasted at both the theoretical and the practical level.[6,20–22]

At the end of the 1970s, Beaver and Rosen[23–25] on the one hand, and Frame and Carpenter[26] elsewhere, introduce a new dimension that has to do with the relationship between the scientific 'size' of a country and its proportion of articles signed in conjunction with other countries. This hypothesis has been corroborated by the Information Science and Scientometrics Unit in Hungary. Schubert and Braun[27] analyze the patterns of international collaboration of 36 countries and define a model geared to assess the 'intrinsic cooperativity' of countries and establish more robust indications ('penetration index') than the simple recount of the number of international publications as described by Frame and Carpenter, arriving at an inversely proportional relationship between the scientific dimensions of countries and their degree of international collaboration. Similarly, international collaboration and information flow has recently been analyzed by Schubert and Glänzel.[28,29] This inversely proportional relationship owes to the need for small countries with limited resources to establish external contacts, and the capacity of the larger countries to internally exploit their research efforts. In this way, the smallest countries find it particularly useful to count on the participation of the greater ones with more important vias of development and more consolidated systems.[30,31]

During the 1980s, Subramanyan presented data on coauthorship in Biochemistry and Engineering[32] and a revision on the topic, whereas Moed and Tijssen analyzed international collaboration involving the Netherlands.[33] Data retrieval was systematized in major international organisms such as the National Science Foundation's Science and Technology Indicators series,[34] as well as in the reports by the OECD[35] and the French Laboratoire d'Evaluation et de Prospective Internationales, as part of its Micro-Evaluation program.[36] One key methodological contribution at the end of the 1980s was the appearance of the work of Shrum and Mullins[37] about graph methods for clustering and distance mapping, obtained through multidimensional scaling methods applied to scientific networks.

The year 1990 was witness to a number of conferences and studies centered on collaboration,[38–40] and visual displays of networks of collaboration began to proliferate. The vast majority of the co-authorship networks (at different levels of aggregation) attempt to depict the density of connections among the aggregate members. Their analysis and standardization may involve the use of symmetric indexes (Salton cosine, or the Jaccard or Persson index[41,42] or asymmetric indexes such as the Probabilistic Affinity Index,[43] in conjunction with some mapping technique or method to create the graphic representation.[44,45]

Another matter dealt with in the early 1990s was the positive correlation between the Impact Factor (IF) of a journal in which an article is published and, by extrapolation, the number of citations received by the article, and the participation of more than one author (individual or institutional).[46–49] As a general rule, the greater the number of partners, the greater the impact of the documents produced, particularly in the case of international collaboration.

In the wake of these antecedents, the objective of the present study is to show visual representations that help analyze different aspects of scientific collaboration at the international level, combining indicators of production and of impact. On the one hand, we identify the international facet of research by following the fluxes of knowledge seen in the number of publications, establishing the main geographical axes, and representing the domain relationships analyzed in conjunction with other countries. In this representation, we show which relations are most frequent (reflected in the size of the sphere), what degree of visibility is achieved (distance from the central node), and how these relationships are affected by the different types of collaboration (position of the orbits). The application, then, is twofold: we can characterize the patterns of communication of a given country, and generate a graphic representation that will serve as an interface for domain analysis and information retrieval.

Material and Methods

The information used came from the Science Citation Index, Social Sciences Citation Index and Arts & Humanities databases of the Web of Science (Thomson Scientific). From the field address, we gathered all the documents pertaining to each of the countries represented with output in 2004. The IF according to the Journal Citation Report (JCR) was taken into account. The registers were exported to a relational database, after which we normalized the data at all levels: institutional, thematic, geographic and with regards to the JCR IF.[50,51] The IF normalization process characterizes by each document taking the IF of the journal in which it has been published from the JCR. These IFs are assigned to each document. Afterwards, they are normalized through a typification process in order to generate values able to maintain the variability at the same time that they homogenize the different categories scales. From these normalized values the Xnac is calculated, by adding the values and dividing them by the total number of documents. The resulting number indicates the average value of the normalized IF of an aggregate. In this way, different sets of documents may be separated, for instance those belonging to a particular collaboration type and then compare them with the total number of documents. Thus, relative indicators may be calculated with respect to the national total, which would enable to determine the different positions in the graph's orbits.

To count records, we used the full recount, in which a document signed by more than one institution or country is considered to belong to each other. The types of collaboration are:

- No collaboration: meaning that the documents are signed by a single scientific institution, regardless of the number of authors or departments involved.
- National collaboration: with documents signed by more than one national institution (national or foreign, that is, there may be some overlap with the international collaboration).
- International collaboration: referring to documents signed by at least one institution from a foreign country.

Finally, the category 'international collaboration' can includes documents published by only one national institution and at least one foreign institution. These documents do not belong to the category 'national collaboration', because there is only one national signing institution. Although the category 'national collaboration' may include documents from the category 'international collaboration, the category 'international collaboration' is not a subset of 'national collaboration' because it contains documents signed only by one national institution which are not included in the category 'national collaboration'. For instance, in the case of Spain, there are many documents signed by only one Spanish institution and one or more foreign institutions and those documents do not belong to the set of 'national collaboration'. The category 'national collaboration', for Spain, includes the documents signed by more than one Spanish institution, regardless of the presence of any foreign institution.

The assignment of ISI categories to vast thematic domains follows the classification now in vigour in the Agencia Nacional de Evaluación y Prospectiva (ANEP).[52] The choice of the field 'Agriculture' was based on its relevance in the subject distribution of each country, taking three variables into account: thematic specialization, standardized IF and volume of output, as described in previous studies.[51–53] The indicators presented, in either tabular or graphic form, are: total output, number of collaborating countries, output from international collaboration (documents signed by more than one foreign country), and IF within its particular field and adjusted according to type of collaboration.

At this point, we were able to use the data to build a heliocentric network of international collaboration, using at random different countries from the Hispano-American realm, as represented in the 'Atlas of Science' project[54] of the SCImago Group.[55] The representation occupies the maximum space available, and is characterized by a central node (country analyzed) and a number of surrounding nodes (collaborating countries)

Table 1: Number of documents per country/Number of documents per type of collaboration

	Spain	*Brazil*	*Mexico*	*Cuba*
ndoc	35 412	18 507	7876	714
without	14 224	6953	2760	180
domestic	10 747	11 554	2530	218
international	12 110	5608	3247	410

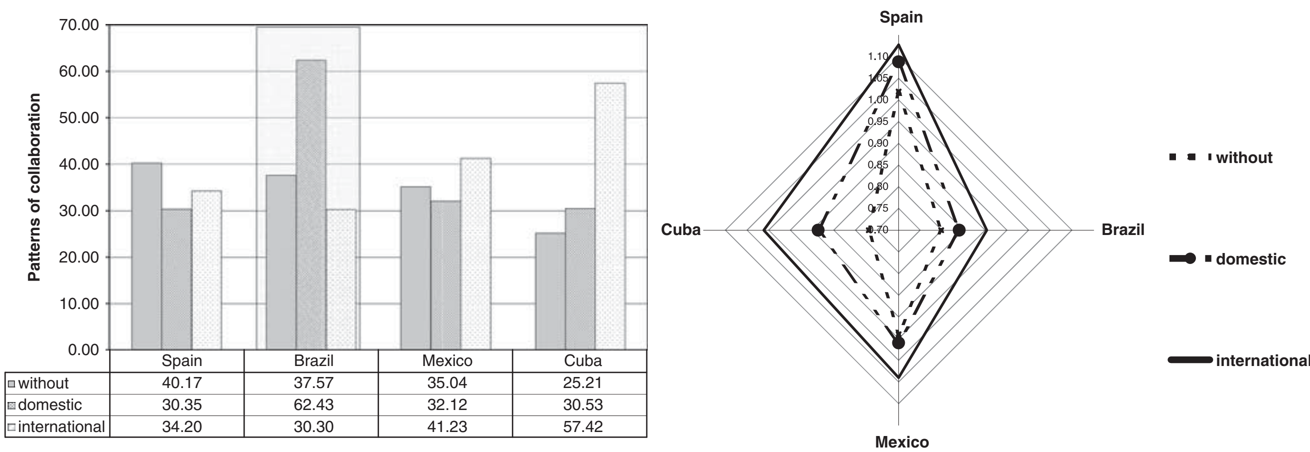

Figure 1: Percentage of documents by types of collaboration and impact factor per country. *Note*: The rectangle is meant to visually show the country with the highest rate of documents in domestic collaboration and with the lowest number of documents with international collaboration.

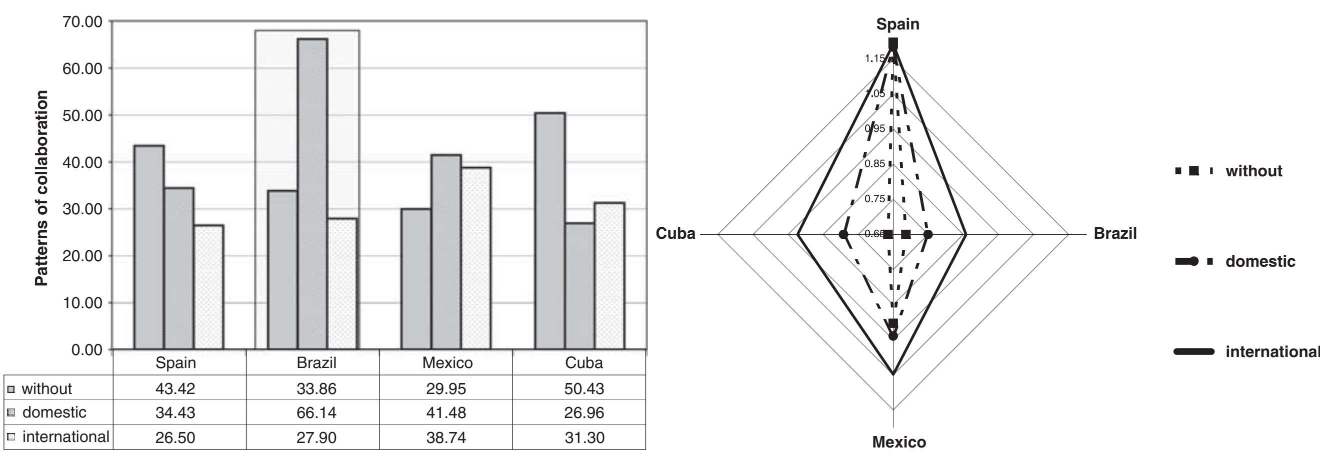

Figure 2: Percentage of documents by types of collaboration and impact factor per scientific field. *Note*: The rectangle is meant to visually show the country with the highest rate of documents in domestic collaboration and with the lowest number of documents with international collaboration.

that orbit around at a greater or lesser distance, depending on the intensity of their relations with the central node.

The size of each sphere represents the percentage of documents produced in collaboration with the country in question, whereas the colour reflects the membership of each country to a distinct geographic region. Depending on the area, the number of collaborating countries will vary, and although the present study displays all the nodes, there are cases such as Biomedicine or Physics for which it is impossible to show with any clarity all of the collaborators. Therefore, some threshold or cut-off point is needed to facilitate visualization. First, the percentage of collaboration of each country with respect to the total production in that area was used as the threshold, and those countries whose contribution is over 1 per cent were included. This means that our threshold is variable and is established by the particular features or idiosyncrasies of a given subject area. The same criteria have been used in previous work.[56]

Table 2: Number of documents in Agriculture/Number of documents per type of collaboration

	Spain	*Brazil*	*Mexico*	*Cuba*
ndoc	1034	1577	728	115
without	449	534	218	58
domestic	356	1043	302	31
international	274	440	282	36

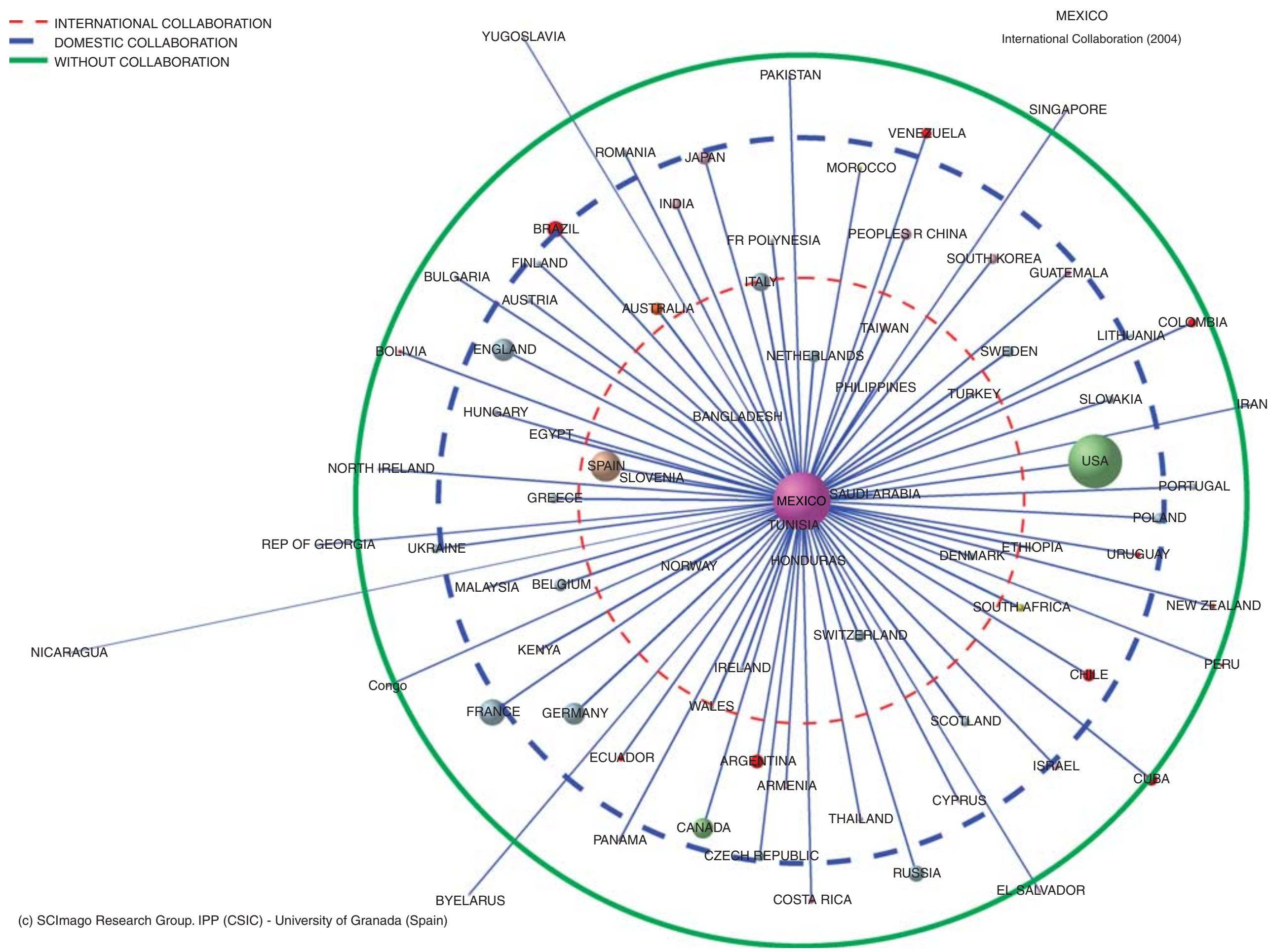

Figure 3: Heliocentric network of international collaboration – Mexico 2004.

The next step is determining how we are going to represent impact values (distances from the central node). In order to standardize the data (the length of the links), the following formula was applied to the values of the NIF (normalized IF):

$$Z_j = \frac{X_j - 1}{X_{\text{nac}} - 1}$$

X_j= It is the normalized average impact factor of the set of documents from the different collaboration types (j) in a subject area, Xnac= It is the set of published documents' normalized average impact factor of a country.

In order to generate a graphic display of the network, we used Pajek[57] software, together with the Kamada Kawai algorithm,[58] taking the option 'similarity' into account; in this way, even if the thickness of the relationships remains constant, their length varies. Length is inversely proportional to visibility in terms of impact. Thus, one can rapidly detect which countries are the most visible (the closest) and with which only limited visibility is achieved (more distant). The definitive network was exported to an Scalable Vector Graphics (SVG) format,[59] which allows the user to zoom in on any area of the screen, or move around in any direction.

Moreover, in order to compare the visibility of the intellectual association with a given country, three concentric circles can be seen with the relative values of impact according to the type of collaboration: no collaboration (green), national collaboration (blue) and international collaboration (red). Thus, we can situate the countries in terms of their membership to a peripheral circle (less visible), and determine which ones are above the average impact according to type of scientific interchange.

Results

Production and rates of collaboration

The number of documents retrieved for each one of the selected countries (ndoc) and the number of

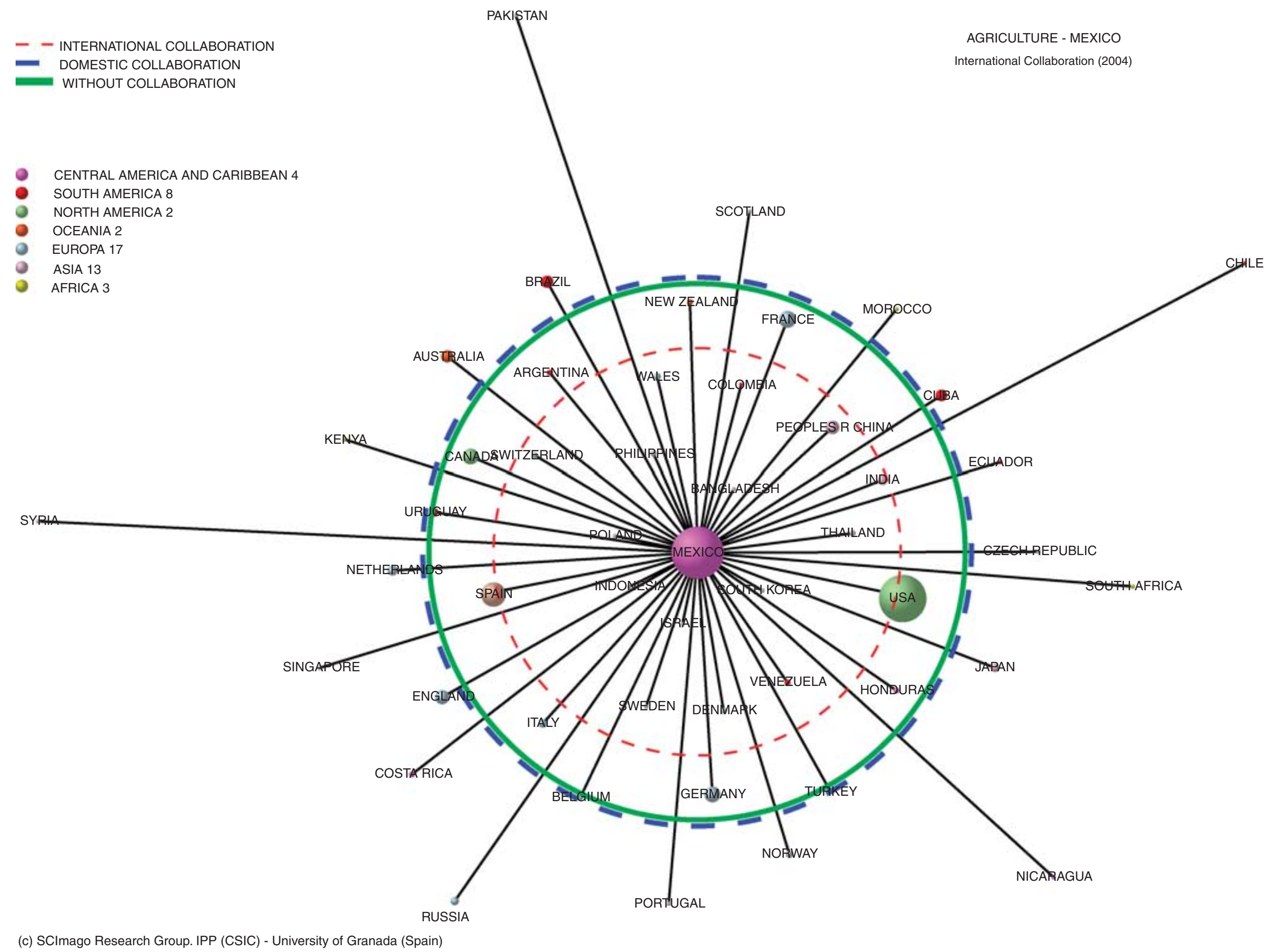

Figure 4: Heliocentric network of international collaboration in Agriculture – Mexico 2004.

documents according to type of collaboration are presented in Table 1.

With respect to the patterns that emerge for each country and area (Figure 1), the proportion of documents with no institutional collaboration is greater in the countries that have greater overall output. Brazil is seen to be the top scientific producer in the Latin-American realm; and while it shows the lowest rates of international collaboration, and the highest amount of production without collaboration, it is also the country that that relies most heavily on the cooperative efforts of its national institutions (62.43 per cent). This would come to corroborate the hypothetical inverse relationship between volume of output and rate of international collaboration. At the same time, the standardized impact of the countries studied here is depicted, according to the type of collaboration. The documents with international collaboration are the ones achieving the greatest levels of impact, followed by the documents involving domestic collaboration.

The country with the greatest volume of output in Agriculture is Cuba (16 per cent), followed by Mexico and Brazil (with proportions between 8 and 9 per cent). Far behind lags Spain, with a scarce 3 per cent share (Table 2, respectively, Table 1)

The patterns of publication for the area of Agriculture differ with regard to total production in all the countries studied except Brazil, which shows parallel trends between total output and output in Agriculture (Figures 1 and 2). Mexico and Cuba present the highest rates of international collaboration, whereas the country with the best results in terms of visibility is Spain (Figure 2).

Heliocentric networks of international collaboration

Note: The users may consult the maps freely. They are accessible in this url: http://www.ugr.es/~zchinchi/colabora.html.

The heliocentric representation of Figure 3 depicts the international collaboration of Mexico in all fields of scientific output. Around the central node, at a greater or lesser distance, orbit those countries with which Mexico collaborates; their relationship is represented by

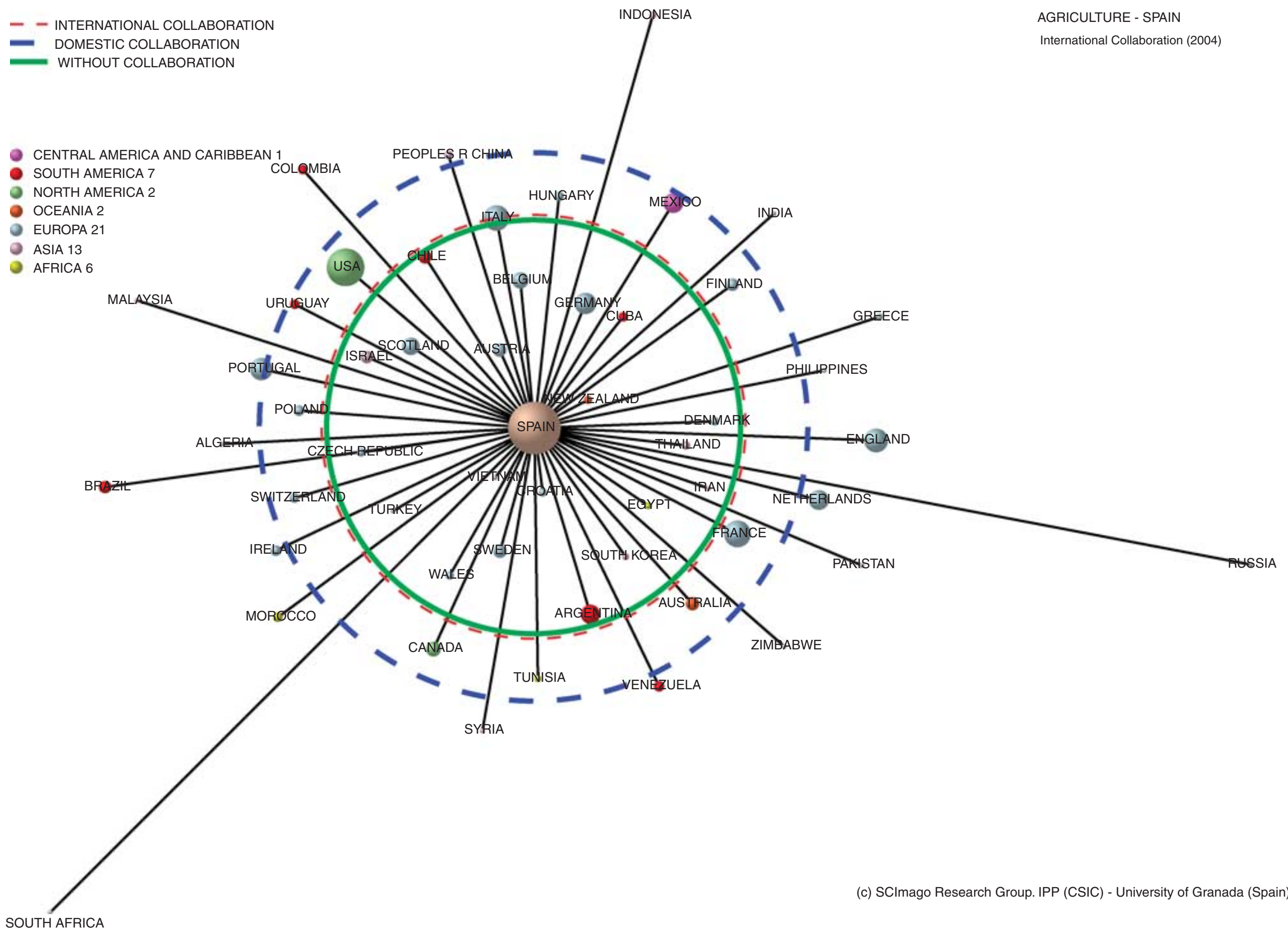

Figure 5: Heliocentric network of international collaboration in Agriculture – Spain 2004.

a line whose distance is inversely proportional to visibility/impact. Thus, one can quickly spot with which countries more is published (greater volume) and with which one is more visible (closer to the center). The map leads us to a noteworthy finding: although international collaboration increases impact, it does so to widely differing degrees. Figure 3 shows how collaborative countries such as Yugoslavia, Singapore, Iran, El Salvador, Belarus, Nicaragua and Georgia have global impact values lower than those obtained through documents without collaboration. However, if we look at the results according to field of knowledge, we can see just what role each country plays and how the patterns of collaboration differ in terms of impact (position of the orbits for each specialized field). A combined reading of the data (Figures 3 and 4) shows Colombia to have relatively poor results in terms of visibility (an orbit without collaboration) on the global level; yet it is a good partner in the field of Agriculture (international orbit) (Figure 4). The situation of the orbits differs from one map to the next. Note that in Agriculture in Mexico, there is little variation between the documents without collaboration and those involving institutional collaboration.

Relationship between the rates of collaboration and their visibility

In general terms, we can confirm that there exists a positive correlation between the IF and the participation of more than one author (institutional or foreign; see Figures 1 and 2: IF per country). This is shown by the position of the orbits in the maps (Figures 4–7) the relative nearness to the central node is represented by red (the closest), blue and green orbits. Surprisingly however, the countries with more associative research efforts are not the most visible ones. In fact, the countries found to collaborate most on the international level are Mexico and Brazil, though Spain, with the least collaboration, achieves better visibility regarding production on the whole.

Therefore, in Spain we have an abnormal or inverted pattern. Note that the documents signed without any collaboration attain slightly higher values of impact than those produced in domestic collaboration; and the latter, in turn, have greater impact than those of international collaboration. This leads us to surmise that Spain is a good potential partner for other countries, as research done at

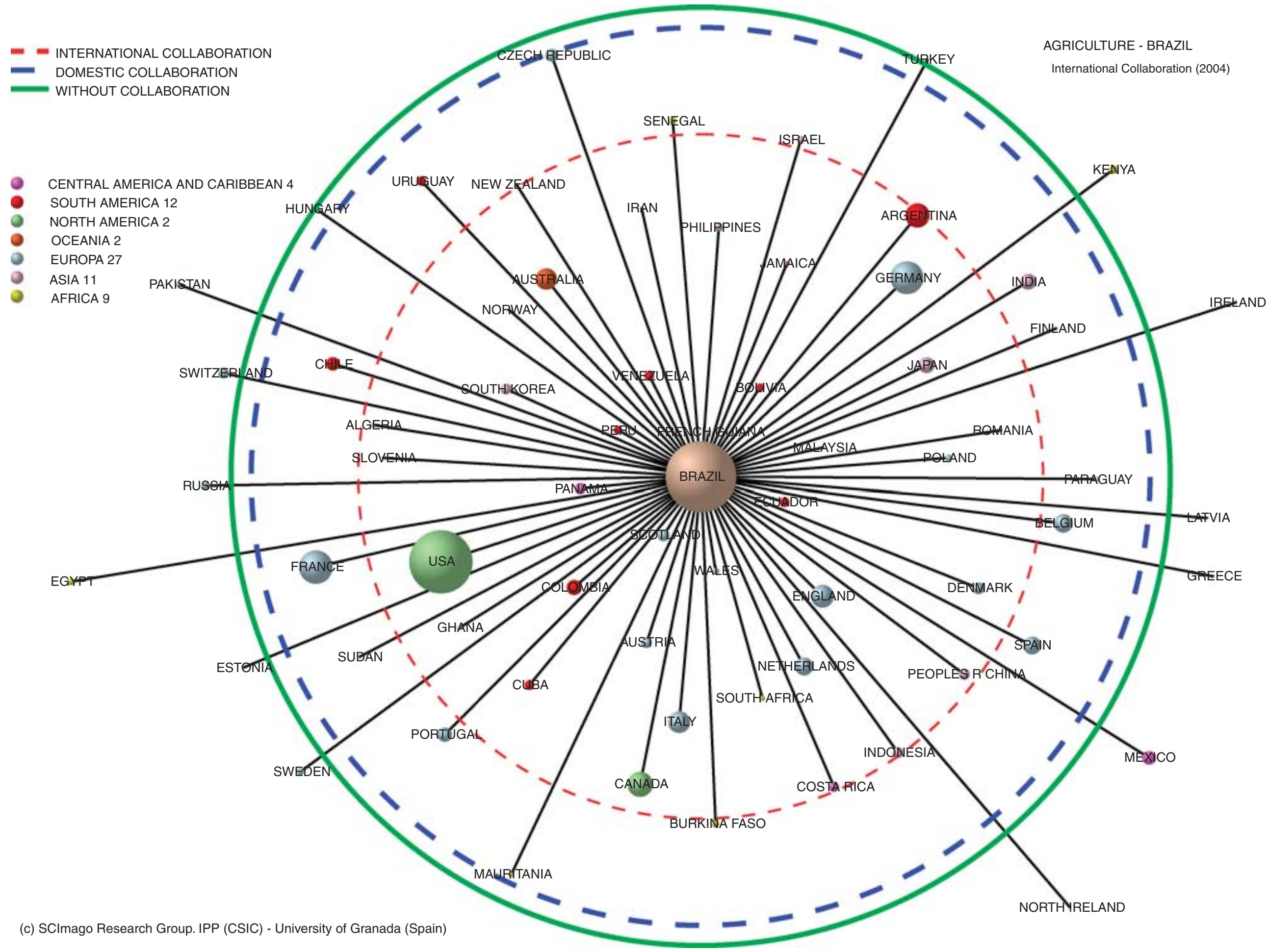

Figure 6: Heliocentric network of international collaboration in Agriculture – Brazil 2004.

the domestic level is internationally recognized. Agriculture is one of the areas with the greatest visibility in this country, as seen for some years in the rankings put out by Thomson Scientific.[60] Thus, there are certain fields in which the universal patterns are not fulfilled (international collaboration implying greater impact than the documents produced without collaboration).[61]

Through a quick comparison of the positions of the countries (nodes) of each map, we can see with which countries one obtains the best visibility (nearness of central node) regardless of the volume of output (size of sphere) mentioned above. We can thereby corroborate that Spain is a better partner for Brazil (Figure 6) than vice versa (Figure 5), as the documents co-authored with Brazil are situated in the orbit of its national impact (Figure 6); whereas for Spain, that visibility is below the minimal values of impact (periphery). Spain is also seen to be a beneficial partner for Cuba (international orbit – Figure 7), though Mexico (national orbit – Figure 4) reaps the greatest benefits in terms of visibility.

If we focus on the international orbit, we can easily see which are the best partners in scientific production. Cuba produces the documents with greatest impact in conjunction with Brazil, Peru, Canada, Uganda, Kenya, Spain and France. Meanwhile, with Sweden, Scotland and Costa Rica, it obtains the lowest values (Figure 7). Spain collaborates with 26 countries, with which it obtains a much higher impact than the national average (orbits of without collaboration and of international collaboration). Among these are 14 European partners, six Asian ones and three South or Central American ones: Argentina, Cuba and Chile (Figure 5). For Brazil, the Central and South American partners are strong points both in output and in visibility, with the exception of Chile, Uruguay, Paraguay and Mexico (Figure 6). In Mexico, there is no such beneficial relationship with the neighbours, and only Venezuela and Colombia act as visible allies, although the United States and Spain would appear to be determinant in the degree of international collaboration (Figure 4).

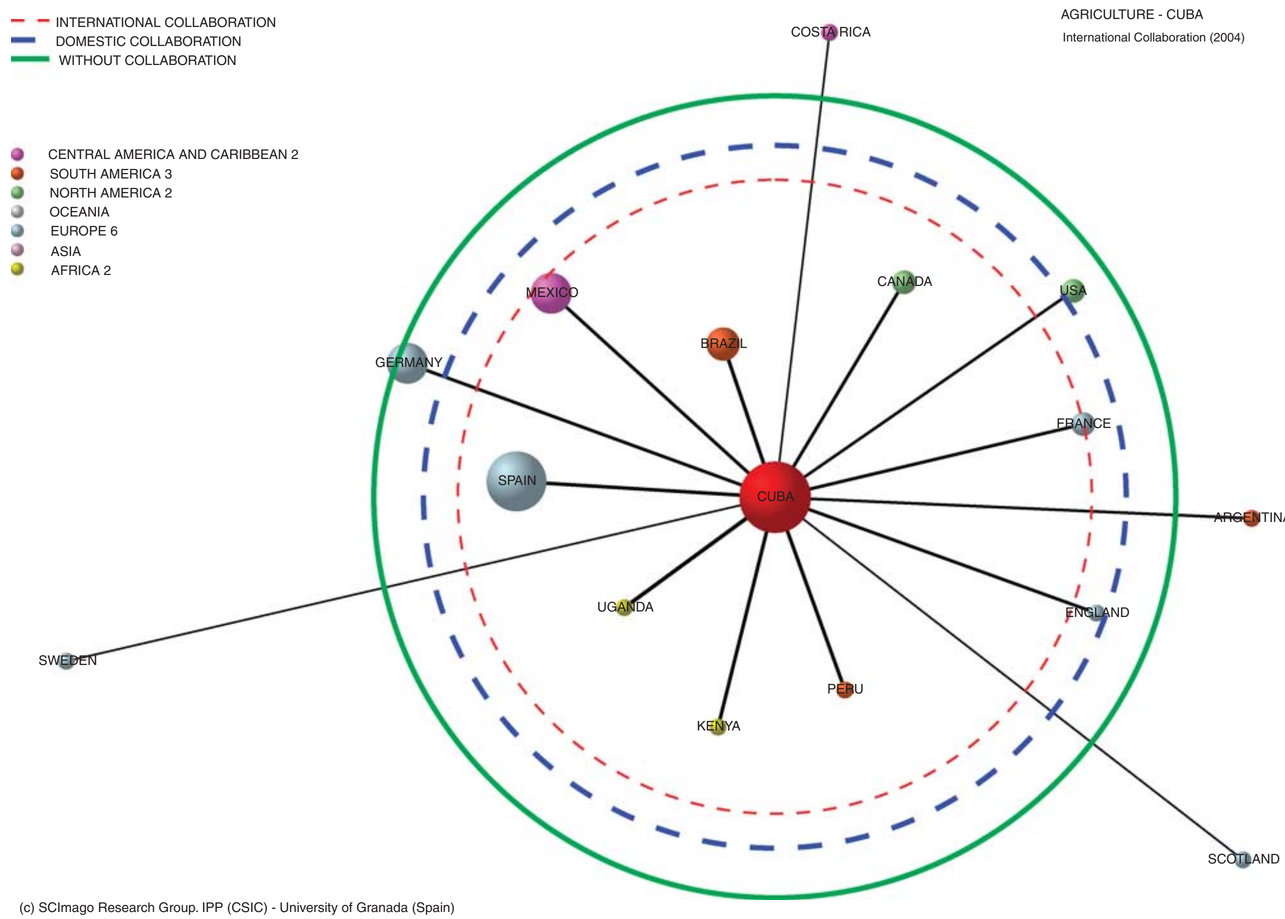

Figure 7: Heliocentric network of international collaboration in Agriculture – Cuba 2004.

Number of partner countries and main geographic axes

Brazil and Spain establish the most ample networks of collaboration insofar as the number of collaborating countries (66 and 52 countries, respectively). Mexico relates with a lesser number of countries (48) yet has a higher proportion of collaboration. Conversely, Cuba is the country with the least relations (15 countries), despite having the greatest production in the field. These relationships are shown in the maps (links) as well as in the geographic areas (colour of nodes) that are most akin for each country.

While Asia proves to be an important associate for Mexico, Spain and Brazil (who, respectively, collaborate with 13, 13 and 11 Asian nations), Cuba has no relations with the Asian continent, or with Oceania.

Brazil is the country that collaborates the most with Africa (9) and with Europe (27), followed by Spain (6 and 21, respectively). Moreover, Brazil maintains relationships with nearly all the countries of South America (12) and Central America (4), probably owing to its geographic proximity[62] and cultural and linguistic similarities.[63,64] Spain establishes collaborative contact with only one Central American country (Mexico), and seven South American ones.

Conclusions

As the corpus of specialized literature has evidenced, the analysis of scientific collaboration provides relational information that allows one to enrich purely bibliometric studies with the schematic representation of the domain in question, thus giving insight as to how information flows within the system.

The most significant contribution of this methodology is the visual representation of relationships of international collaboration in view of the impact or visibility achieved, and the clear presentation of orbits that change depending on the type of collaboration they reflect, revealing the relative benefits in terms of visibility that certain associations may afford. Moreover, this approach yields information about the volume of scientific production and helps identify the main geographical axes of research. Altogether, the displays provide data that can be easily and intuitively processed, for interpreting the currents of scientific output at any level of aggregation (regional, national, thematic, institutional, individual, and so on). For these reasons, we believe it is a very useful aid for the study of patterns of collaboration.

At the same time, our analysis leads us to pose some additional questions and foresee new research fronts. For instance: Which are the most visible research fronts within a given specialized field? What institutions are behind the bulk of the work from the leading countries? What role do these institutions and countries play in the network? What are the political policies regarding research and development that seem to lead to more productive scientific scenarios? Such gaps in our understanding can gradually be filled by complementing bibliometric studies with additional data that serve to contextualize and solidify the body of information available. At present, work in our particular setting is centered on the graphic depiction of secondary relationships among collaborating countries; that is, not just analyzing relations with the main node.

It is our hope that this tool will prove useful, then, not only for scientists on the front lines of research, but also for the policymakers in the background. Such representations can be consulted during the process of establishing scientific alliances, as they provide subtle information about the permeability of a given domain, the relative strengths and weaknesses of the participating countries and institutions, and the repercussions – in terms of output and its visibility – of geographic proximity.

A prototype of this System of Information as an interface for processing data at different levels of aggregation can be viewed within the framework of the 'Atlas of Science' project of the SCImago Group.

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