International Collaboration in Medical Research in Central and South America

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Abstract: This paper characterises the patterns of international medical research in Central and South America. The objective is to ascertain countries' capacity to establish intra- and extra-regional scientific collaboration. The methodology used combines bibliometric techniques and social network analysis. Publication patterns are characterised by production volume, specialisation, visibility and collaboration through Scopus database. The results show the recent increase in Central and South American medical research production and citations has raised the region's presence and participation in the international scientific arena. Although this growth is partly associated with the inclusion of new journals in the Scopus database, the rise in the number of medical research papers has doubled the overall increase. When output is broken down by inter- and extra-regional collaboration, the growth rate proves to be slightly higher for the former than the latter. The "scientific dependence" of small or developing countries would explain their high collaboration rates and impact, since their output is essentially marginal and anecdotal. Hence the term "satellite countries." Advanced countries account for most of the world's output and citations. Assuming that impact (citations per paper) reflects the use made by researchers of previously generated knowledge, the evidence shows that the major producers use the knowledge generated by their own or neighbouring countries. This would explain why impact is so highly concentrated in the most productive regions. The need to incentivise intra-regional relationships must be stressed, but without establishing boundaries, i.e., international initiatives should also be supported. The possible influence of geographic, idiomatic and cultural proximity is likewise identified. Lastly, the conclusions are discussed, along with proposals for future research.

Keywords: bibliometrics, Central and South America, medicine, intra-regional scientific collaboration, extra-regional scientific collaboration, social network analysis, hybrid indicators.

Introduction

The growing intensity of scientific collaboration is one of the most visible features of the transformation taking place in science. Ever since the nineteen sixties (Price, 1965) collaboration has been the rule rather than the exception. The trend in most scientific disciplines for research teams to expand is an indication of a move toward greater efficiency in the use of the available resources, as well as toward increased productivity and higher prestige and visibility. In short, the acceleration of scientific progress has been at least partly driven by intense partnering between scientists and research groups in different countries (Beaver, 2001; Glänzel, 2001).

One of the objectives pursued in many developed countries is to further collaboration at all levels and across all disciplines through incentives and other scientific policy measures. These incentives are geared to furthering the inter-relationships developed in scientific research for essentially three reasons. Academically, partnering establishes positive feedback from the scientific system via the import of new knowledge and the integration of that knowledge into institutions and research processes. Economically, it enhances the ability to use the available resources cost effectively.

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Politically, it aids in the translation of research efforts into innovation (Framework Programme or EUREKA in Europe), with the incorporation of assessment and structural tools and the reinforcement of project assessment and monitoring, primarily on the grounds of the results of scientific activity and the application of indicators that reflect international scientific criteria (Commission of the European Community, 2003; Ministry of Science and Technology, 2004).

The significance and preponderant role played by collaboration were highlighted in a meeting of OECD science and technology ministers held in 2003. That meeting delivered a statement in which all levels of scientific and technological collaboration were declared to be of utmost importance for the furtherance of sustainable development as a basis for social and economic independence in developing countries, as well as to favour researcher mobility and add to participants' cultural and scientific *acquis* (OECD, 2003).

Along similar lines, CYTED (Programa Iberoamericano de Cooperación en Ciencia y Tecnología para el Desarrollo: Ibero-American Cooperation for Scientific and Technological Development Programme) was founded by the Latin American and Caribbean countries, Portugal and Spain to further cooperation among research teams in its member countries.

The Ibero-American Research Area (Espacio Iberoamericano del Conocimiento, EIC) is another regional initiative that fosters ongoing cooperation in higher education and academic and researcher mobility in pursuit of regional integration and effective cooperation in Latin America. In a context in which knowledge is regarded as the basis for social, economic and cultural development (16th Ibero-American Summit, 2005), the EIC is defined as the "scope in which to further regional integration and strengthen and foster interaction and cooperation as a means of generating, circulating and transferring knowledge for mutual and complementary benefit, improving the quality and enhancing the relevance of higher education, scientific research and innovation on which to base the region's sustainable development." This idea is no different from the premise underlying the Commission of the European Union's Lisbon Strategy, which identified knowledge as the grounds for economic competitiveness.

Against that backdrop and from a perspective aligned with scientific policy, analysis of collaboration is justified as way to strike an approximate balance between what is expected and what is obtained, between the effects of programmes and measures and their implementation over time. Such an analysis furnishes information useful for decision-making with respect to areas such as avant-garde research, the formation of research teams, mobility programme planning and strategic alliances respecting future collaboration. It also contributes to avoiding the duplication of effort by maximising both human and material resources, among many other advantages. At the same time, academically speaking, it compares cooperation trends (up, down, flat) in countries or areas of knowledge and identifies where partnering is more or less active and visible (Chinchilla & Moya, 2007).

Objectives

The characterisation of international collaboration in medical research in Central and South America and each country in the region is broached in this context of general public interest, with a view to addressing its strengths and weaknesses from two standpoints. The first is countries' capacity to engage in scientific collaboration both intra- and extra-regionally. The second is the identification of publishing patterns from which to appraise the effects of partnering networks on scientific production and impact, using bibliometric indicators such as output, degree of specialisation, visibility and popularity. The aim is to furnish information with which to interpret countries' networking potential as a vehicle for reaching the levels of scientific productivity and competence pursued by their governments. Two of the specific objectives sought in connection with the comparison of intra- and extra-regional collaboration are:

- to identify the countries that hold central or strategic positions in collaboration networks
- to determine the countries benefitting most from their relationship dynamics in terms of area productivity.

The study also proposes new methodology that combines indicators for use as a decision-making tool able to characterise production and the effect of intra- and extra-regional collaboration on the productivity of the region's main science producers.

Material

The source of the production and citation data for the target countries in 2003-2007 used in this paper was the open-access portal *SCImago Journal & Country Rank (SJR) and the SCImago Institutions Rankings (SIR)*. These products were developed by the SCImago Group from the information contained in Elsevier's Scopus database (SCImago, 2007).

Some authors have qualms about using international class databases for analysing geographically peripheral regions (Sancho, 1992; Whitney, 1992; Garfield, 1997; Herrero & Moya, 1999). Their indisputable contention is that a substantial amount of local and regional knowledge is left out of such databases (Gómez, Sancho, Moreno & Fernández, 1999), due as much to the strategies adopted by the researchers in these regions with respect to the production and transfer of scientific knowledge as to database publishers' editorial criteria. Since, moreover, English has traditionally been the predominant language in these sources, the difficulty entailed in assessing the research conducted in non-English speaking countries has narrowed the vision of their production. Similarly, these countries' presence on the international science arena appears to be more a result of the specific situation of each subject area (Spagnolo, 1990) or the connections of certain lines of research with world science (Shrum, 1997) than of regional behaviour. For the reasons set out below, however, the information used in this study overcomes some of these objections and affords other advantages.

With respect to other multi-disciplinary sources such as the Web of Science (WoS), the journals listed in the Scopus (Elsevier B.V.) database provide wider geographic and subject area coverage, with a greater presence of peripheral regions as well as of disciplines such as engineering and technology that to date have been scantly represented in the Thomson Reuters database. The source chosen, then, provides uniform and balanced coverage (Moya et al., 2007), with a higher proportion of peripheral countries and a broader variety of languages (Arencibia & Moya, 2010).

For medical research, LILACS (Literatura Latinoamericana y del Caribe en Ciencias de la Salud, Latin American and Caribbean Health Science Literature) and MEDLINE are among the recommended sources for studying Latin American literature. However, these bases include the first author's affiliation only, which is a major obstacle to their use in collaboration studies, particularly compared to WoS or Scopus, which furnish all authors' affiliations. Scopus lists all the journals contained in MEDLINE, affording an additional advantage over WoS. Choosing Scopus will also facilitate supplementary future studies based on citation analysis, because whereas WoS shows only the first author in bibliographic references, Scopus includes up to eight. Although this number is still fairly small for fields with high co-authorship rates, it is a definite improvement over WoS (Zhao & Strotmann, 2011). For all the foregoing, Scopus was used as the source of information for this study, given its greater suitability than other international databases of similar size for analysing medical research collaboration among countries in the target region.

Methods

The earliest sociological studies on scientific collaboration were conducted in the nineteen sixties, but it was not until the nineteen nineties when the use of data and methodologies for their analysis began to grow and diversity (Yamashita & Okubo, 2006; Sonnenwald, 2007). Furthermore, while scientometric studies themselves cannot do justice to the dynamics of scientific collaboration (Wang, Wu, Pan, Ma & Rousseau, 2005; Heinze & Kuhlmann, 2008), co-authorship constitutes one of the most obvious and best documented types of evidence of the existence of relationships among researchers and, by extension, among the institutions and countries funding or conducting R&D+I (Glänzel & Schubert, 2004). Co-authorship is seen, then, as an expression of collaboration through which possible knowledge networks can be at least approximately identified (Bordons & Gómez, 2000; Anuradha & Urs, 2007; Velden, Haque & Lagoze, 2010).

The methodology used in this study combines bibliometric techniques and network analysis, an approach that has proven to be useful to determine aggregate behaviour based on a study of structurally established social relationships (Kejzar, Cerne & Batagelj, 2010; Vargas, Minguillo, Chinchilla & Moya, 2010; Perianes, Olmeda, Ovalle, Chinchilla & Moya, 2011). In other words, the attributive analysis characteristic of bibliometric indicators is supplemented with a study of the relationship patterns and actors' positions that have a direct impact on behaviour in the immediate environs as well as global network results and interactions (Wasserman & Faust, 1994).

The units of analysis were the 36 countries located in the target area. Collaboration analysis was preceded by the calculation of bibliometric indicators on production volume and citations to position medical research in the regional and international context. The indicators used are: **ndoc,** the number of papers published by each country; **% ndoc,** the percentage of each country's output over the regional (% ndoc R) or world (% ndoc M) total; **Ncit,** the number of citations received by each country along, as with output, with the respective percentages of the total for the region (% Ncit R) and the world (% Ncit M)**; ia**, the activity or specialisation index, reflecting the relative activity in a given subject area in terms of the degree of specialisation, understood to mean the relative effort devoted to that area; and **ai**, the attractivity index, which characterises visibility based on the relative number of citations received by a given scientific unit. A value of one is an indication that the number of citations received by the unit (institution, region, discipline...) in question is in line with the nation- or world-wide mean, or whatever other reference is adopted. A value of over one signifies "added value" or "strength" and means that the target unit received more citations than the reference unit. A value of under one denotes the opposite.

Bibliometric indicators for collaboration and matrix generation

Another indicator found was ncol or the number of papers involving international collaboration, subsequently broken down in the relationship study into papers written in collaboration with extra-regional authors and papers written in collaboration with authors from countries within the region.

The findings on the number of co-authored papers were used to build symmetrical matrices for the years 2003 to 2007. A matrix was built for 2003 with two partitions, shown and analysed in this paper by way of example. The first partition provides information on collaboration with all the countries with which the 36 target countries collaborated. The second is a subset of the first, showing information only on collaboration among the target countries themselves. Taken together, the two identify each country's role in its intra- and extra-regional relations, facilitating subsequent comparisons of network indicators. Two inter-country similarity networks were generated for the same year. In the first, the Pajek software D1 index was used, which factors in the number of first degree neighbours shared by two nodes, irrespective of the number of instances of collaboration among them. In the second, a similarity network was generated based on the number of instances of mutual collaboration among countries. Finally, a list of neighbours was drawn up to generate a heliocentric network showing each country's relationships with all the others. This was based on the information on the number of internationally co-authored papers produced by the country in question and the citations per paper received for the papers published with each partner.

Relationship indicators and structural analysis

The following relationship indicators were also calculated. The nodal degree is the number of nodes (countries) to which each network node is directly related. This measure depends on the size of the network, for it represents the total number of relationships in a node with respect to the maximum number possible. It is the simplest indicator for estimating social capital. The existence of many relationships is no proof of their quality, however, nor does it reflect the intensity of inter-nodal associations (Mrvar, 2000; Hanneman & Riddle, 2005). Betweenness furnishes information on countries' capacity to serve as bridges between other nodes and provides insight into the control exerted by a given node over other nodes' communications. (A node with a low nodal degree but a high level of intermediation may carry substantial weight, for if it disappeared from the network, the nodes connected by it would not exhibit the same degree of interrelationships (Mrvar, 2000). Node closseness is its capacity to connect to other nodes in the network and indicates the number of stops it

takes to reach another vertex. A high degree of proximity means being well positioned, which in turn facilitates access to resources that contribute positively to node activities. The clustering coefficient indicates the density of the relationships among a given node's circle of partners. It is equal to the ratio between the number of links between a node and its neighbours and the total number of links among all nodes in the network. This indicator is normalised because it takes account not only of the number of each node's neighbouring links and the total in the network, but also of the maximum nodal degree in the network (Watts & Strogatz, 1998). Values close to one denote a high rate of collaboration with partners, but also among these partners. Figures close to zero, by contrast, mean that the node is the sole inter-partner link (Barábasi, 2002). The popularity indicator proposed by Perianes (2009) was also calculated. This hybrid indicator is the result of an innovative combination of two known indicators, one structural and the other bibliometric: a node's clustering coefficient and its scientific output. The expression used for these calculations is shown below. Popularity index: $CC'(v) \times ndoc(v)$, where ndoc(v) is the total output of node v in a given period of time. The clustering coefficient relates the bibliometric popularity indicators (number of papers) to collaboration with this node. A new measure can consequently be obtained to distinguish between two nodes (in this case, countries) with the same output. The more "popular" of the two is the one with a more cohesive network of collaborators. Two variations were used in this study: in the first the calculation was run for the total number of papers and the second for only the papers involving international collaboration. This approach is designed to determine possible differences between popularity as a country attribute and popularity due to its output as a network component.

Network visualisation

Two types of collaboration networks are shown: sociocentric and heliocentric. The Kamada Kawai (1989) algorithm was used to position the nodes in both. This method assigns coordinates to the nodes to adjust the distances between them as closely as possible to the theoretical distances (Vargas-Quesada, 2007). The size of each node represents its output and the lines indicate inter-country relationships. The colour (shades of grey) is a measure of intensity. Pajek software (Batagelj & Mrvar 2003) was used to calculate and display both indicators. For the heliocentric network, the methodology applied was an adaptation of the methodology proposed for international collaboration networks, factoring in collaboration and visibility in terms of citations (Chinchilla, 2005; 2010). The map was charted on the basis of the number of articles co-authored by the country studied with each other country, taking a list of neighbours as the point of departure. The representation occupies the maximum space available, and is characterised by a central node (country analysed) and a number of surrounding nodes (collaborating countries) that orbit around it at a greater or lesser distance, depending on the intensity of their relations with the central node. The size of each sphere represents the number of documents produced in collaboration with the country in question, whereas the colour reflects the geographic region where the country is located. The lines denote the citations received for the articles written in collaboration with each country. The networks are depicted on the basis of value similarity, yielding links with identical thicknesses but variable lengths.

The partnering countries orbit around the central node at a greater or lesser distance and their relationship is represented by a line whose length is inversely proportional to visibility. This type of graphic has been used to quickly identify the countries with which a country publishes most (highest volume) and with which it is more visible (closer to the centre). This analysis shows the main geographic axes and to what extent and how these relationships impact visibility, depending on the type of collaboration. Moreover, two concentric circles give the average number of citations per paper for the country's overall production (dashed line) and the average for papers involving international collaboration (solid line). This information can be used to draw comparisons between the visibility of the associations with different countries. Countries can therefore be classified in terms of their position in a peripheral circle (less visible) and whether or not they lie above the average impact for each type of scientific partnering (Chinchilla, 2005, Chinchilla & Moya, 2007; Olmeda, Perianes, Ovalle & Moya, 2008; Chinchilla, Vargas, Hassan, González & Moya, 2010).

This graphic can be used for both static and dynamic descriptions of an institution, region, country or scientific discipline. An analysis of the variations in these relationships provides insight into their stability, expandability and visibility, enabling anyone concerned to monitor joint projects and strategic alliances, among others.

Results

World and regional medical research output. Countries' role.

World-wide, a larger volume of papers is published on medicine than any other subject area. Medical research accounted for around 30 % of world output between 1996 and 1999. Thereafter, its prevalence declined due primarily to the relative increase in the number of papers published on other subjects, such as engineering, technology and social science (Scopus, 2010). Depending on the country, this increase may have been related to the database effect and policies on subject coverage, or on the characteristics of specialisation in each region. Medical research patterns in Latin America differed from the above, both volume- and trend-wise. Firstly, even at its highest, the percentage never exceeded 24 %. Secondly, while research in this discipline declined steadily until 2004, it turned upward from then on, climbing back to the values recorded at the beginning of the period (**Figure 1**). These developments narrowed the earlier six-point gap with respect to the rest of the world, bringing the region into line with general global trends.

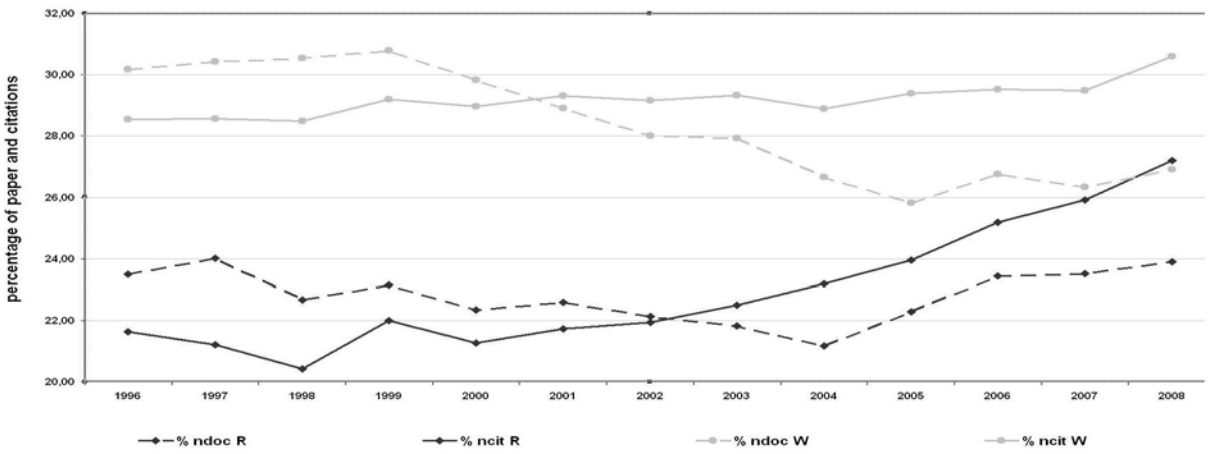

Figure 1. Variation in percentage of medical papers and citations in Central and South America and the world (R = region; W = world).

Note the high correlation between output volume and citations received (Moya, et al., 2009) and the relative uniformity in the pattern of variation in the world and regional domains. Nonetheless, the citation rate grew more rapidly in Latin America than in the world at large, narrowing the gap at an even faster pace than observed for output. While this might be initially believed to be related to an improvement in publication patterns in the region and greater visibility, the proven fact that the inclusion of journals in international citation indices leads to a decline in visibility (Zitt, Ramanana & Bassecoulard, 2003; López, Moya & Moed, 2008) clashes with that assumption.

The target region accounted for 2.88 % of world output in the period studied, with a mean increase of 14 % (taking 2003 as the baseline), while its contribution to world-wide medical research was slightly lower, at 2.45 %. The ten major producers in the region in all fields were Brazil, Mexico, Argentina, Chile, Venezuela, Colombia, Cuba, Puerto Rico, Uruguay and Peru. Country by country, the percentage contribution was very irregular, particularly at the lower end of the classification. Brazil grew at a higher rate than the world overall, climbing to nearly 1.51 % of the global total, compared to 0.58, 0.39 and 0.23 % for Mexico, Argentina and Chile, respectively, and 0.1, 0.09 and 0.08 % for Venezuela, Colombia an Cuba.

The country output classification was the same for medical research. Brazil accounted for nearly 60 % of the regional total, followed by Mexico and Argentina with much more modest values, 16 and 12 %, respectively. The gap was even larger with Chile (7.5 %), Venezuela and Colombia (4.5 % each), Cuba (3 %), Puerto Rico and Uruguay (1.5 % each) and Peru (1.1 %). None of the remaining countries accounted for even 1 % of the regional total (**Figure 2**). Some countries' percentage of the world total changed. Output declined in Argentina and rose in Venezuela, for instance. Finally, overall medical research output grew in all these countries, giving the region a greater presence world-wide, as shown in the sub-graph on the right in Figure 2.

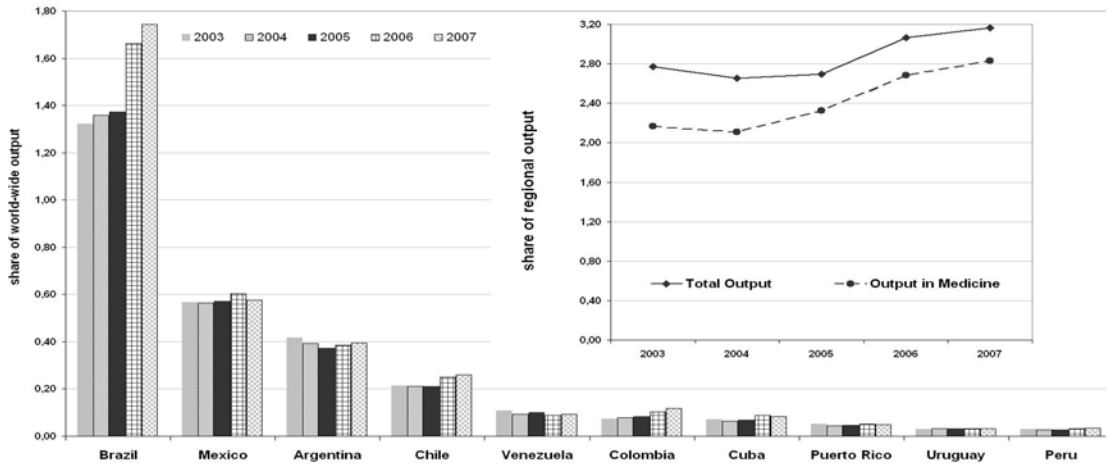

Figure 2. Medical research output for the 10 major Latin American producers: variations in the percentage of total world production.

Specialisation, attractivy index and output

Figure 3 is a multivariate graph positioning the 20 countries with the highest output in the region from 2003 to 2007 by area of specialisation and attraction index (compared to the regional mean). The importance of medical research against overall scientific production can be visualised on this graph. Each country's output is shown by the size of the sphere, which ranges from Brazil's 57 370 scientific articles to Guadeloupe's 170 papers. A reference sphere representing 250 papers is shown in the upper right quadrant. The specialisation or activity index is graphed on the x-axis and the attraction index on the y-axis. The countries positioned in the upper right quadrant had higher than the regional average values for both variables; the ones in the lower right quadrant had higher than the regional mean values for specialisation only; the countries with higher than the average regional number of citations are positioned in the upper left quadrant; and the lower left quadrant contains the countries that failed to reach the regional standard in either of the two variables. A country's output reflects not only activity in the field and its capacity to generate knowledge, but also its specialisation by subject area. The two, moreover, need not follow the same pattern. This is the case of the countries in the lower left quadrant, where some of the most productive nations, such as Argentina, Mexico and Chile, are positioned. Venezuela, Costa Rica and Puerto Rico are positioned in the upper right quadrant, with a high attraction index but very modest production volumes. This may be related to their participation in international projects, due to which scientific collaboration would play an important role in the position attained, as discussed below.

The highest performers in the upper right quadrant, Guatemala, Barbados, Nicaragua, Peru, Trinidad & Tobago and Guadeloupe, have fairly small outputs. While the focus in the present analysis is on the impact of production (measured by citations and specialisation), these data must be interpreted with

caution. The results for countries in this quadrant with a substantial production such as Cuba, Colombia, Peru and Jamaica, are actually far more significant. The most prominent finding, however, is Brazil's position, for despite its high output, both its specialisation and citation figures exceeded the regional means. This represents added value, for it is more difficult to place a large than a more modest volume of papers in the highest citation and specialisation positions.

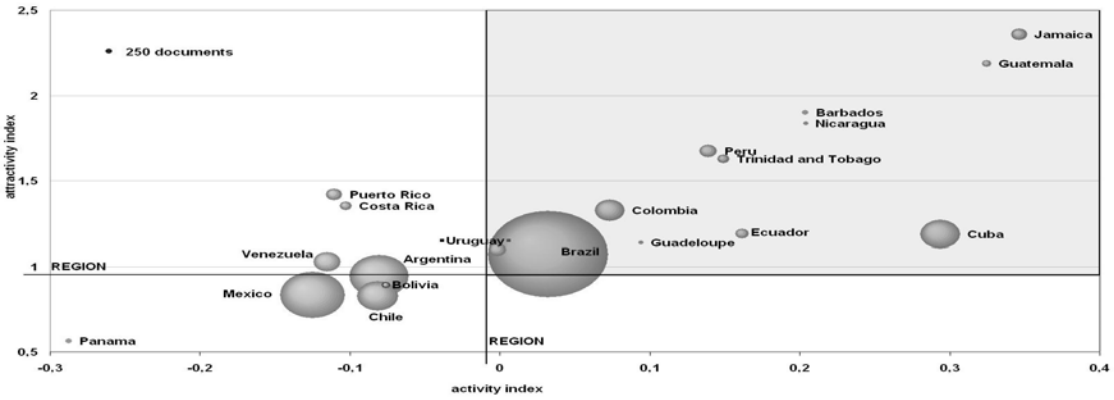

Figure 3. Specialisation, attraction index and output.

Collaboration

The literature (Melin & Persson, 1996; Melin, 1999; Chinchilla, 2005) has shown that for aggregates of whatsoever sort, output is inversely proportional to their rate of international collaboration. The smallest countries exhibit the highest rates of international collaboration, as Figure 4 shows, although surprisingly, Jamaica and Trinidad & Tobago have rates similar to the values observed for countries with much larger outputs. Four areas are differentiated on the graph in **Figure 4** for readier visualisation. From the top down, the countries where the rate of international collaboration is less than 30 % are listed first (Brazil only); the second area lists countries where the rate is 30 to 50 % (Mexico, Argentina, Chile, Venezuela, Colombia, Jamaica and Trinidad & Tobago); in the third, the rate is 50 to 70 % (Cuba, Puerto Rico, Uruguay, Ecuador, Panama and Guadeloupe); and finally, the fourth shows the countries whose medical research output is practically a satellite activity, with international collaboration accounting for over two-thirds of the total (Peru, Costa Rica, Bolivia, Guatemala and Nicaragua).

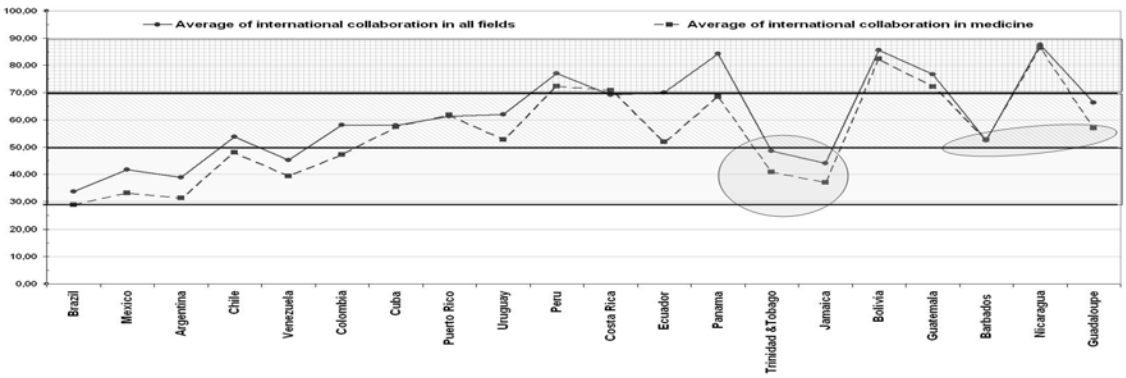

Figure 4.Percentage of international collaboration in all fields and in medicine.

Figure 4 also compares international collaboration in medicine (broken line) to international collaboration in all areas (solid line). In most countries the collaboration rates are slightly lower in medicine than in all subject areas, but this is especially the case in Ecuador and Uruguay. In Cuba,

Puerto Rico, Costa Rica, Barbados and Guadeloupe, however, the percentages are the same, an indication that nearly all research conducted in collaboration with other countries is associated with medicine. This information should be taken into account, together with the specialisation and attraction indices, to ascertain how open or dependent a country is with regard to foreign influence. The countries where international collaboration is highest would be the so-called "satellites", with similar percentages of international collaboration in their overall and medical research outputs.

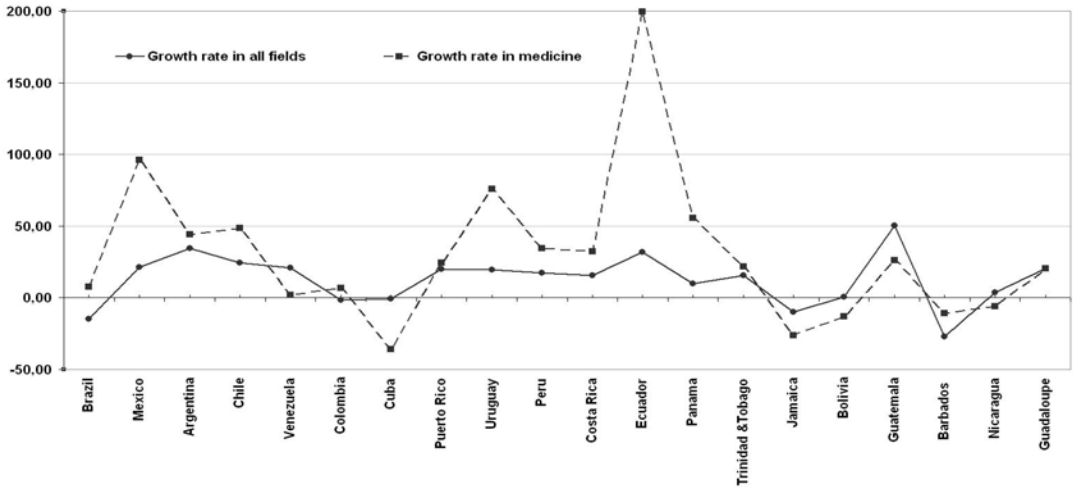

Figure 5. Growth in international collaboration in all fields and in medicine

Finally, all the countries in the region have tended toward greater internationalisation. The highest growth was observed for Ecuador, where it trebled, and Mexico, where it nearly doubled, followed by Uruguay, Panama, Chile, Argentina and Peru (Figure 4). This pattern, which is the general rule in the international context, had a few exceptions in the region studied: Cuba, Jamaica, Bolivia, Barbados, Nicaragua and to a lesser extent, Venezuela and Colombia.

Intra- vs extra-regional international collaboration

Making this distinction makes it possible to determine whether intra-regional collaboration is growing and how it impacts consolidation both in the Ibero-American Research Area (Espacio Iberoamericano de Investigación) and internationally. By combining the values for the battery of indicators designed for this study, information can also be gleaned on the variations in the number of participating countries, the number of papers involved and the effects of these associations.

Table I gives the variation in the number of countries involved in international collaboration by region. Two rows are shown for Latin America, one for intra- and the other for extra-regional collaboration. The bottom rows give the percentage of papers by type of collaboration.

An upward trend can be observed in the number of papers co-authored both intra- and extra-regionally, as well as in the number of regional partners, which grew by 25 % (first row for Latin America), bringing intra-regional collaboration to 73 %, while collaboration with other countries grew by only 6 %. The increase was also much higher for the number of intra- than for the number of extra-regional papers (48.74 versus 25 %).

The number of countries from other regions grew by 23 % (from 110 countries in 2003 to 135 in 2007), and the nations involved were located in a wide variety of regions. Eastern Europe, the Near East, Western Europe and Asia accounted for the largest number of partners, with 75, 66.7, 60 and 54.5 %, respectively, although proportionally more Asian than European countries were new to the

list. Depending on the area, the participation of Southern African countries grew substantially. Relations with the Pacific region, while scant, held steady throughout the five-year period.

Region	2003	2004	2005	2006	2007	Growth Rate	Number of partner countries per region	% of partner countries per region
Asia	15	20	17	18	18	20,00	33	54,5
Central Africa	9	7	8	12	11	22,22	24	45,8
Eastern Europe	14	13	13	13	18	28,57	24	75,0
Central and South America (*)	**28**	**29**	**28**	**31**	**35**	**25,00**	**48**	72,9
Central and South America (**)	***35***	***37***	***37***	***36***	***37***	***5,71***	**48**	
Middle East	10	7	8	10	10	0,00	15	66,7
Norther Africa	3	2	2	4	3	0,00	5	60,0
North America	2	2	2	2	2	0,00	2	100,0
Pacific Region	2	2	3	3	3	50,00	28	10,7
South Africa	8	12	9	12	14	75,00	28	50,0
Western Europa	19	19	20	18	21	10,53	35	60,0
Number of countries (***)	82	84	82	92	100	21,95	242	41,3
Percentage of partners countries	33,88	34,71	33,88	38,02	41,32			
% intra-regional collaboration	16,51	20,41	21,42	22,09	24,55	48,74		
% extra-regional collaboration	58,33	60,42	58,33	64,58	72,92	25,00		

(*) Includes only countries partnering with countries in the region
(**) Includes all Central and South American countries engaging in international collaboration
(***) Includes only non Central and South American countries

Table 1. Variation in the number of countries collaborating in medical research.

Collaboration patterns in Latin American countries

The network depicted below reflects the relationships among countries by their choice of partners for medical research. The distance between nodes and the intensity of the lines are determined by the affinity between countries in terms of the number of neighbours concurring on the same two nodes, regardless of the frequency. The size of the nodes is proportional to medical research output and the colours distinguish three groups by their collaboration rates. Countries with international collaboration rates of under 30 % are shown in black; grey denotes rates of 30 to 50 % and white rates of 50 to 100 %.

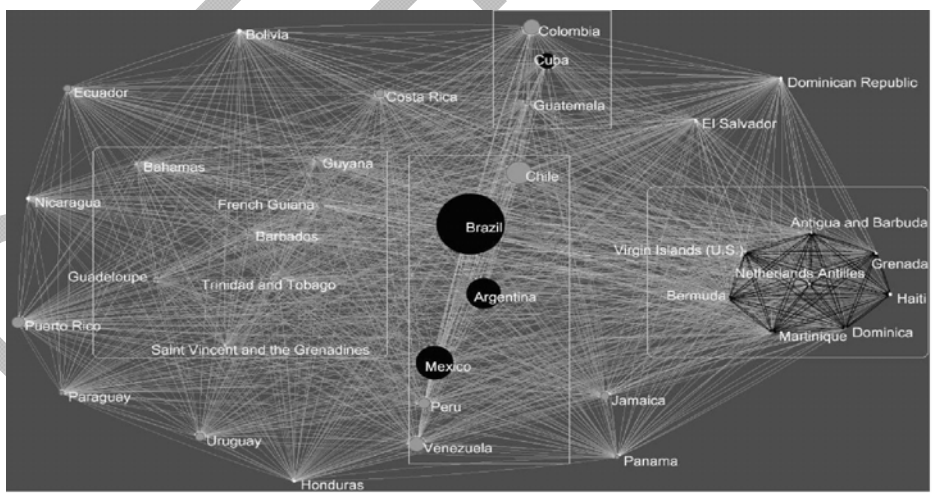

Figure 6. Collaboration network by number of neighbours, 2003. Available at: http://www.scimago.es/zaida/figura6__scientific_collaboration_network_neighbors.jpg

Here the analysis is positional, i.e., associated with the place occupied by each country on the network, in which possible inter-country similarities in terms of collaborative behaviour in the region are identified. The cluster of countries on the right, for instance, partner only with countries outside the region; in the present context, this group is disconnected from the rest of the network. These are, moreover, satellite countries with small outputs and a high collaboration rate, partnering essentially

with the world's major producers (North America and the most scientifically significant European countries). The centre of the network is occupied by three trios forming a nearly vertical line: Colombia, Cuba and Guatemala; Chile Brazil and Argentina; and Mexico, Peru and Venezuela. These clusters comprise the region's main producers, as observed from the size of the spheres and relatively low collaboration rates.

Another cluster, including some of the Caribbean islands and the Guianas, can be identified left of centre. This group is characterised by intense partnering with countries outside the region and with Latin American countries of a similar size. One of the factors possibly contributing to these connections is linguistic affinity, inasmuch as English is the official language in most of these countries. Geography and subject area are other possible influences, the former for reasons of proximity and the latter because the groupings may be a result of specialisation in each country.

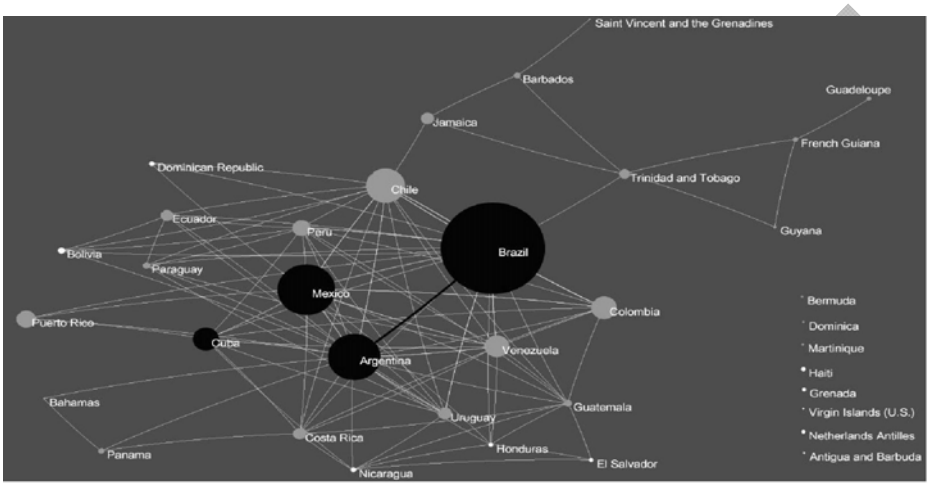

Figure 7. Collaboration network by frequency of relationships, 2003. Available at: http://www.scimago.es/zaida/figura7_scientific_collaboration_network_relations.jpg

Figure 7 shows partnering among the countries in the region in 2003. The sphere size and colour scheme are as in Figure 6. In this case, the distance between the actors reflects the total number of joint projects. Unlike the preceding figure, this image contains a list of countries on the lower right that were included in the general analysis but which are disconnected from the rest of the network because they engage only in extra-regional collaboration.

The central part of the map revolves around Brazil as the strategic partner for the rest of the countries. Brazil and Chile are the only countries that collaborate with the English.-speaking satellite nations positioned in the upper right corner of the network. The rest of the network is positioned around the most productive countries, forming clusters which, as in the preceding case, are geographically oriented. The Central American countries are clustered at the lower part of the map and at the lower left, the Caribbean countries on the one hand and Bolivia, Ecuador and Paraguay on the other.

Comparison of intra- and inter-regional networks: indicators of centrality, cohesion and popularity

Generally speaking, Brazil exhibits the highest intra- and extra-regional centrality values, followed by Argentina. Chile, in turn, exhibits indisputable potential with regard to intra-regional centrality and proximity, greater than observed for Mexico. In the broader extra-regional context, however, Chile ranks higher than Mexico only as an intermediary. The map is a clear indication of these four countries' capacity in these two contexts. It confirms Brazil and Argentina as central pillars, followed by Chile and Mexico due to their good strategic positioning and large number of relationships. Moreover, not all countries perform better extra- than intra-regionally: examples are Guatemala, Honduras and Peru. This may be explained by the implementation of collaboration policies geared more to the regional than the extra-regional sphere, probably due to a focus on local subjects or induced by geographic proximity.

Countries' strategic position as intermediaries is generally higher on the international than the regional arena. The strongest countries in terms of other indicators, namely Brazil, Argentina and Mexico, are located even more advantageously as international intermediaries, while Trinidad & Tobago stands out clearly as a regional hub. Curiously, the importance of the Central American countries (Guatemala, Honduras and Nicaragua) and Barbados as intermediaries is lower in the extra- than the intra-regional context.

The proximity indicator reveals the importance of being positioned in broad networks. All countries' communication potential rose, improving their positions in terms of ease of establishing contacts. Greater partnering capacity led to greater access to material and social resources, which ultimately translates into more highly developed scientific activity. In this case, the smaller countries (Antigua and Barbuda, Grenada, Bermuda, Dominica, Haiti and Martinique among others) benefitted most from international collaboration. This would confirm Persson's (2010) hypothesis mentioned earlier.

By contrast, cohesion, in terms of the intensity of relationships, was found to be weaker when the countries were placed in a broader context. In other words, intra-regional relationships are stronger than the extra-regional variety. The most notorious examples in this regard are Colombia, Ecuador, El Salvador and Puerto Rico. Guadeloupe, Honduras and Trinidad and Tobago, with the highest coefficient in the extra-regional network, stand at the other extreme, an indication that they may have pursued greater international visibility by partnering with countries outside the region.

The popularity indicator analyses the benefit in terms of productivity deriving from the collaboration strategy implemented, by examining the values obtained from two standpoints. The first is the relationship between the two types of popularity in the intra- and extra-regional spheres. The second focuses on the significant differences in each version of the indicator by comparing intra- and extra-regional collaboration. In both cases, the index combines a country's total output or total output involving international collaboration with the implications of the number of associations established, the density of the resulting relationships and the degree of intermediation acquired. In the intra-regional context, the scientific majors rank highest in total and international collaboration-related popularity, in the following order: Brazil, Mexico, Argentina, Chile, Colombia and Venezuela. While these countries' total popularity is more or less similar, minor differences are observed in popularity linked to international collaboration, particularly for Cuba, Puerto Rico and Venezuela. In the extra-regional domain, popularity follows similar patterns. The strongest countries rank highest. In terms of total popularity, Cuba ranks very high, ahead of Venezuela, which is followed by Puerto Rico. Cuba's popularity slides while Peru's rises substantially when popularity is viewed from the standpoint of international collaboration.

Comparing the popularity index from the intra-/extra-regional standpoint shows that while Cuba's popularity is higher outside the region, Colombia ranks better within it. Analysed from this perspective, but in terms of output involving international collaboration, Colombia plays a significant role intra-regionally while Peru is prominent extra-regionally.

International collaboration: heliocentric network

Another aspect of interest, in addition to the description of collaboration in terms of frequency and similarities in publication patterns, is the number of citations received per internationally co-authored medical research paper for each of the countries studied. The window chosen as a baseline for the citations received in the period 2003-2008 was the scientific output in 2003 involving international collaboration, as represented in the preceding networks. An example of the results of collaboration in terms of visibility and impact on the international scientific community are shown in Figure 8, which depicts the heliocentric network for Cuba's internationally co-authored output in medicine.

The partnering countries orbit around the central node at a greater or lesser distance and their relationship is represented by a line whose length is inversely proportional to visibility measured as citations per paper. This type of graphic has been used to quickly detect the countries with which co-

authoring volume is largest and which afford the greatest visibility (closest to the centre), as well as to identify the main axes (Chinchilla, 2005, Chinchilla & Moya, 2007; Chinchilla, Vargas, Hassan, González & Moya, 2009).

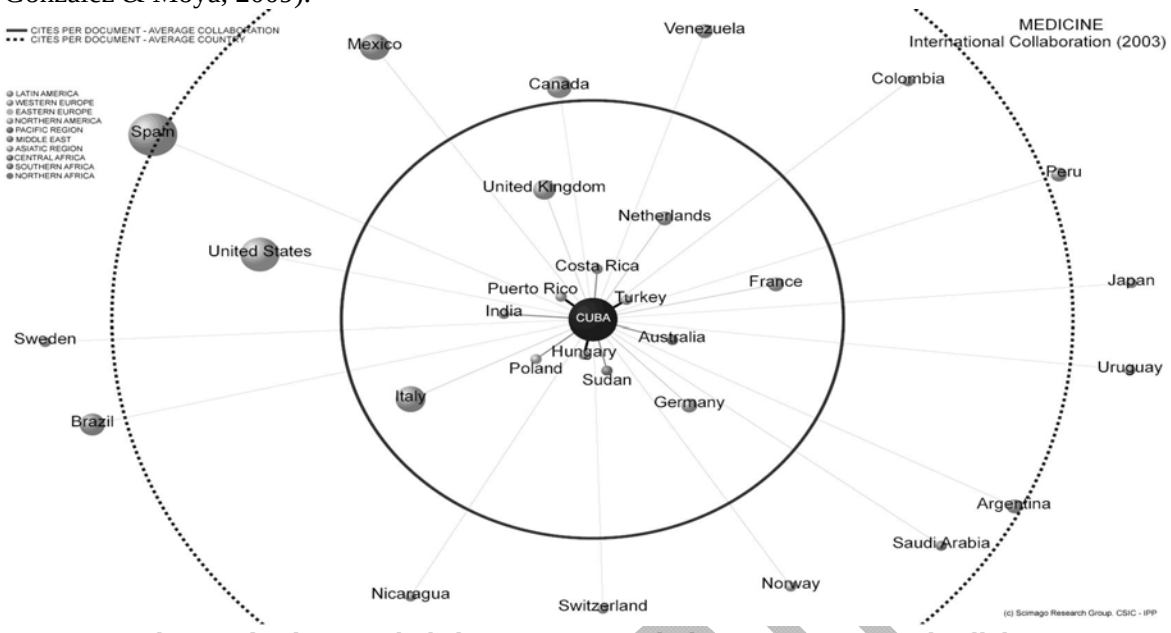

Figure 8. Cuban medical research: heliocentric network showing international collaboration, 2003. Available at: http://www.scimago.es/zaida/figura8_international_scientific_collaboration_network_medicine.jpg

The map shows, interestingly, that while international collaboration enhances visibility, not all countries are equally effective in this regard and consequently not all benefit from collaboration to the same degree. The countries located in the central orbit (citations per paper received by internationally co-authored papers) are the countries with which the largest number of citations are achieved, although substantial differences in size can be observed. Hence, while the citation rate is somewhat lower with countries such as Italy, United Kingdom, France, Germany and The Netherlands, a higher volume of studies is conducted in collaboration with these nations. Higher citation rates are attained with countries closer to the centre, such as Poland, Turkey and Hungary, but the number of papers involved is fairly small. Despite Spain's predominance in terms of the number of papers written in collaboration, that production is among the least visible, along with the output with all the countries positioned outside the orbit representing the mean number of citations per paper received by Cuban production overall (broken line).

Discussion and conclusions

The recent increase in Latin American medical research production and citations has raised the region's presence and participation in the international scientific arena. Although this growth is partly associated with the inclusion of new journals in the Scopus database, the rise in the number of medical research papers has doubled the overall increase. Medicine is, then, a high growth area in the region as well as a sphere with enormous world-wide potential in terms of output, citations and collaboration.

When output is broken down by inter- and extra-regional collaboration, the growth rate proves to be slightly higher for the former (25 %) than the latter (23 %). While the increase in absolute terms is small, the fact that both values rise at nearly the same rate is an indication of cohesion and similar trends in scientific research across the region. In other words, the policies designed to further regional collaboration may be bearing fruit. An earlier study on collaboration between Argentina and the European Union showed no apparent relationship between co-authorship of scientific papers and the partnering that stems from inter-country scientific cooperation agreements, whose purpose seems to be primarily formal (Miguel & Ugartemendía, 2010). Consequently, the motivation for partnering should be sought in strategic alliances associated with programmes and projects in which collaboration with certain countries is requisite, such as in the EU's framework programmes, the CYTED programme and similar.

All the countries in the region are improving their position and productivity from the standpoint of visibility and specialisation. Visibility values are high for Brazil, as well as Cuba and Colombia. Brazil's performance is particularly significant, for its attraction index (a measure of citations) is high, despite the fact that its domestic journals are listed in the Scopus database. This is striking, for as a rule the inclusion of such journals paradoxically leads to a decline in a country's mean impact. Here, however, the presence of these journals in the SCielo database, which covers medical research very thoroughly, may have contributed to raising the country's visibility. The BIREME, a specialised centre under the auspices of the Pan-American Health Organisation, which sponsored this regional initiative, is headquartered in Brazil. Future studies will include in-depth research on the effect of SCielo on participating countries' visibility.

As might be expected, the smaller countries exhibit the highest international collaboration rates, an indication of their capacity to establish international relationships. Most of the countries with significant values in this regard are small: Jamaica, Guatemala, Barbados, Nicaragua, Trinidad and Tobago, Guadeloupe and Ecuador. In some cases, size is even anecdotal, for the position attained is explained by specialisation or the fact that collaboration favours visibility, particularly in countries that publish a very small number of papers. The countries with the largest outputs have low international collaboration rates. Collaboration would not appear to affect production in such countries, by contrast to the situation in smaller nations.

These patterns have been widely discussed in the literature, which has identified a negative correlation between the size of any geographic domain and the percentage of internationally co-authored articles (Schubert & Braun, 1990; Katz, 1994). This correlation may be explained by the fact that most researchers in smaller regions seek out colleagues from abroad, for their only hope of networking in a given research community is by working with national or foreign partners (Narin, Stevens & Whitlow, 1991; Melin, 1999). This gives way to a series of considerations. The first is that in Latin America, smaller countries collaborate extra-regionally to offset the size factor. The second is that since larger communities have more personnel, the percentage of domestic or intra-regional collaboration is necessarily greater. The third question is that according to the centre-periphery model, small communities depend more heavily on national and international networks; and lastly, according to that same model, small communities are more dependent on national collaboration to establish international contacts. All these assertions explain the higher proportion of collaboration in smaller communities (Melin & Persson, 1996).

Nonetheless, forming part of international networks benefits all concerned, for a greater capacity to establish such relationships affords greater visibility. One premise in this regard, generally accepted for several decades, is that the number of citations received is positively correlated to the participation of more than one (individual or institutional) author (Lewison & Cunningham, 1991). The number of citations increases with the number of authors, particularly when the partners are from different countries (Katz & Martin, 1997; Glänzel, 2001), although this trend differs depending on the country, sector and scientific discipline (Glänzel & Schubert, 2001). In a recent study, however, Persson warned that in the context of citations, international collaboration may vary depending on the units of analysis and aggregation levels used. This author contends that international collaboration is a much more important factor in small countries and their institutions than in countries with a substantial output (Persson, 2010). More than ten years ago, Glänzel, Schubert and Czerwon. (1999) proved that the relationship between international collaboration and citations was more advantageous for less advanced than for more industrialised countries, although the latter also benefitted.

The "scientific dependence" of small or developing countries would explain their high collaboration rates and impact, since their output is essentially marginal and anecdotal. Hence the term "satellite countries." Advanced countries account for most of the world's output and citations. Assuming that impact (citations per paper) reflects the use made by researchers of previously generated knowledge, the evidence shows that the major producers use the knowledge generated by their own or neighbouring countries. This would explain why impact is so highly concentrated in the most

productive regions. One of the implications is that research institutions' repute is influenced by their geography, and such prestige is often unattainable for institutions in less productive or less advanced regions or countries. Put another way, a research institution's neighbourhood may be limited by its global scientific reputation, unless it can reach beyond its neighbourhood through inter-regional alliances with reputed institutions from highly productive regions (SCImago Lab, 2011). Therefore, the position of these small, highly visible countries may be explained by factors such as size, international collaboration rate, area specialisation and the industrial status or stage of emergence of transition economies, while the position of large countries is affected by the environs and the cumulative repute of their institutions.

Structurally speaking and from an intra-/extra-regional standpoint, Brazil has consolidated its position as central pillar. It and the other countries with a high scientific output reach the highest values in these network indicators. Generally speaking, Latin American countries improve their ability to combine forces and communicate in a more international context; here, the smaller countries benefit from collaboration most effectively. Links appear to be stronger in the regional domain, however. The region's major producers also rank highest in terms of popularity, reaching the highest rates both when the domain considered is total regional output and when the context is limited to production involving intra- or extra-regional collaboration. A connection can be established between economic and scientific potential and publication patterns. Geographic, idiomatic and cultural proximity may also contribute to the determination of relationships and collaboration preferences, as suggested in papers by Zitt, Bassecoulard.and Okubo (2000), Schubert and Glänzel (2006), and others. The growth of intra-regional collaboration would thus appear to be a good starting point for developing the Espacio Iberoamericano de Investigación (Ibero-American Research Area).

The need to incentivise intra-regional relationships must, then, be stressed, but without establishing boundaries, i.e., international initiatives should also be supported. The reason is simple. The trend observed over the years is toward greater cohesion among countries in the region from the standpoint of productivity and knowledge transfer, along with a more open attitude, involving a larger number of countries in research. These findings concur with the results reported by Lewison and Cunnigham (1991) and Lewison, Fawcett-Jones and Kessler (1993), Fernández, Gómez and Sebastian. (1998), ; Sancho, Morillo, Filippo, Gómez and Fernández (2006) and Russell (1995) and Russell, Ainsworth, Río, Narváez and Cortés, 2007) and give rise to new questions such as whether the increased cohesion among countries in the region translates into more citations among them; or how the citation rate received by countries relates to their intra- and extra-regional collaboration rates. A recent study on citation flows by type of collaboration and neighbourhood influence concluded that science knows no boundaries. The greater influence of certain countries, regions or institutions over others is due to the existence of a number of immediate environs and the quality or prestige that entails. Influence or the citation rate is greatest in authors' most immediate environs, which need not concur with their national surrounds, and wanes with the enlargement of those environs. The bias introduced by self-citation is maximised in smaller circles. Since the greatest domestically-oriented bias appears in small and developing countries, boundaries should be avoided when establishing relationships (Lancho, Guerrero, Chinchilla & Moya, 2011).

Future papers should continue to explore the origin of these relationships and ascertain whether they appear for political reasons, individual scientists' endeavour or other social, institutional or specialisation-related factors. The aspects contributing to greater scientific excellence must also be studied further by including indicators able to supplement the impact factor, the sole measure currently in place. Future research is also planned to analyse the impact of international relations based on the percentage of papers published by each country in first quartile journals, or the percentage of papers in the top 10 by number of citations. Other input indicators would also have to be included, such as funding, staff size and so on, to determine which countries are most productive from the standpoint of international collaboration in each area, relating inputs to outputs. This would provide a basis for comparing information on publication, collaboration and visibility patterns and progress in analyses of the value and implications of the findings of such studies for the management of countries' and institutions' scientific and technological activity.

Combining relationship analysis and bibliometric techniques has proven to be a useful methodological tool for investigating the patterns that govern collaboration make-up and dynamics, enlarging on the existing knowledge about the researcher (and therefore country, institutional and sectoral) networking. The new formulas for characterising scientific activity based on relationship and hybrid indicators are therefore now viewed as valid analytical and assessment tools for broaching the comparison of intra- and extra-regional collaboration. This analysis constitutes a more in-depth approach to the study of formalised collaboration. It is likewise a method for positioning each country in terms of output and impact based on heliocentric international collaboration networks, which have proven to be a useful decision-making tool and a supplement to hybrid analysis.

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