Jointly published by Elsevier Science Ltd, Oxford and Akadémiai Kiadó, Budapest

Scientometrics, Vol. 44, No. 3 (1999) 441–457

ANALYSIS OF THE STRUCTURE OF INTERNATIONAL SCIENTIFIC COOPERATION NETWORKS THROUGH BIBLIOMETRIC INDICATORS

ISABEL GÓMEZ, MARÍA TERESA FERNÁNDEZ, JESÚS SEBASTIÁN

Centro de Información y Documentación Científica (CINDOC), CSIC, Joaquín Costa 22, 28002 Madrid (Spain)

(Received January 13, 1999)

International scientific cooperation of Latin American countries amongst themselves, with the USA and with the European Union in the period 1991-1995 was studied. The analysis deepens in the differences per subject area and the influence of the regional axis involved. Collaboration patterns differ according to the scientific size of the Latin American countries, the thematic areas and whether a bilateral collaboration or a participation in a multilateral network takes place. Some special characteristics of multi-regional cooperation networks are presented.

Introduction

Globalisation of science reflects itself in an increasing cooperation between nations which originates different types of scientific collaboration networks, frequently enhanced by science policy measures taken at national and supranational levels. Specific programmes were devoted to Latin American (LA) countries or to third countries by the European Union (EU) (*Sebastián,* 1992; *Arvanitis* et al., 1995).

Bibliometric indicators have been used to measure part of the quantifiable results obtained by LA countries through joint research (*Narvaez-Berthelemot* et al., 1992; *Lewison* et al., 1993). Besides, bibliometric studies allow the analyses of trends in international cooperation and the impact of multilateral scientific networks. Co-publications with three or more countries can be used as an indicator of the nature and results of international research networks (*Sebastián* et al., 1998).

We have studied different aspects of LA scientific output in the eighties: through cooperative research projects (*Fernández* et al., 1992) or through co-authorship using Spanish or international bibliographic databases (*Urdín* and *Martín*, 1992; *Galbán* and *Gómez*, 1992; *Sancho* et al., 1994). More recently, in the nineties, we have focused on

0138–9130/99/US $ 15.00

the analysis of the scientific cooperation patterns of LA countries with several geographic regions: amongst themselves, with the EU and with the USA. Different cooperation rates per country were found, and the influence of external partners varied according to the thematic areas and the number of countries involved (*Fernández* et al., 1998).

The aim of the present study is to carry out in-depth analysis of the international scientific cooperation of LA countries with the three geographic regions in each thematic area, trying to visualise the collaboration flows between the partners, and the nature, extent and evolution of the research networks. Bilateral collaboration is considered separately from that in which wider networks are involved.

Methods

Bibliometric co-publication indicators from LA countries amongst themselves, with the EU (of 12) and the USA were obtained from SCI database. CD-ROMs from 1991 to 1995 were used. In spite of the limitations of this database as regards the coverage of LA journals, the fact that all addresses of the authors are registered makes it unique for collaboration studies. The analyses were developed from three principal points of view: subject area, geographic region involved and size of the collaboration network.

Each document was multi-assigned to all the countries involved. SCI categories were grouped into thematic areas following the *Current Contents* classification separating Physics, Chemistry and Mathematics.

Descriptive analysis, graphical methods: k-means cluster analysis and multidimensional scaling with Euclidean distances were used to analyse patterns of countries' activity in thematic areas and different size networks, with SPSS 7.5.

A matrix with the number of co-authored documents between countries was constructed for each area, normalised for the total number of documents of each country. Countries with the same collaboration behaviour towards the others were clustered.

A second matrix was also constructed for each area, with the contribution of each Latin American country to the different size networks. Each country is considered a case and their behaviours in the networks are analysed. Two indexes to quantify the distribution of countries in these networks were introduced.

$$I_i = n_{i2} / \sum_{k=3}^{m} n_{ik} \quad \text{and} \quad I_i' = (n_{i2}/2) / \sum_{k=3}^{m} (n_{ik}/k)$$

- i is each Latin American country
- k is the number of collaborating countries, m being the greatest network size
- n_{i2} the contribution of country i to the network size 2
- n_{ik} the contribution of country i to the network size k.

I_i compares participation in bilateral networks with multilateral ones, while I_i' weighs the different networks inversely to their size. A good correlation between indexes I_i and I_i' indicates that the bilateral collaboration is the most important in all countries and the weighting of the larger size networks does not influence the result. Cluster analysis is calculated with one of those indices (I_i) to observe groups of countries with similar patterns of participation in the bilateral versus multilateral network. The median and standard deviation are calculated for each cluster. A larger median indicates greater participation of the cluster countries in bilateral networks, while a smaller median indicates greater participation in multilateral networks.

To eliminate the strong influence of bilateral collaboration, a third index $I_i'' = I_i/I_i'$ is introduced, where the trilateral versus multilateral collaboration can be observed. It ranges from 0 to 1. The highest value 1 corresponds to trilateral collaboration and smaller values imply greater participation in larger size networks.

Results

The scientific production of LA countries present in SCI database in the period 1991-1995 amounts to a total of 55122 documents. Around 32% of these documents were co-authored with other LA countries, with the EU or the USA. These 17473 documents are the object of the present study.

The collaboration rate per country varies strongly, and is directly related to the countries' scientific size, as has already been described (*Luukkonnen* et al., 1992). In Fig. 1 we can observe that the most productive countries, Brazil, Argentina, Mexico and Chile, have an international collaboration rate below 35%, while the smallest countries present up to 73% of their papers in international collaboration.

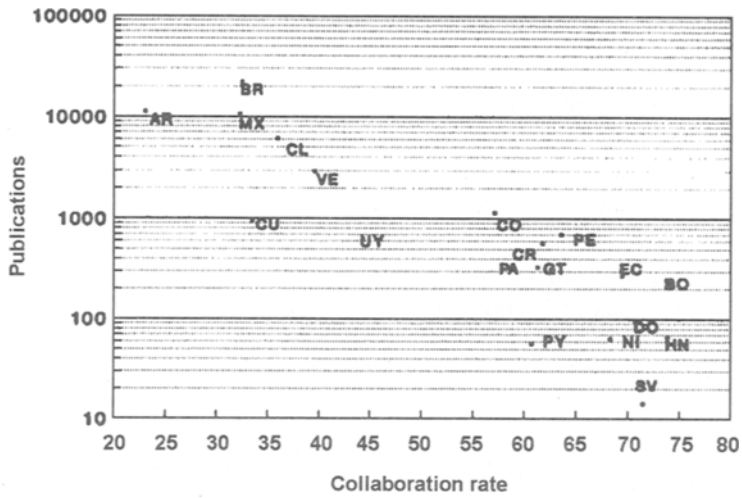

Fig. 1. Collaboration rates of Latin American countries

In a previous paper (*Fernández* et al., 1998) we have analysed the weight of the geographic regions involved. Collaboration with EU countries and with the USA have similar weights, around 44% each; in 6.6% of the documents the USA and EU appear simultaneously, while Latin American countries only in 5.4% collaborate with each other with no extra-regional partners. This small figure is partially due to the small number of LA journals covered by SCI in this period (only 11 source journals in 1995). We would expect inter-Latin American collaboration to be published principally in local journals (*Krauskopf* and *Vera*, 1995).

Thematic areas

The influence of the different geographic axes changes when thematic areas are studied separately. In those areas related to Life Sciences – Clinical Medicine and Agriculture, Biology & Environment (and not as strongly in Biomedicine) – the USA shows a much higher than average participation, while the EU is less active. On the other hand, in technical areas – Chemistry, Engineering, Physics and Mathematics – the EU is the principal partner. In Chemistry the USA participation is particularly low (only 25%). A high percentage of Physics is originated through the simultaneous collaboration of the three geographic regions (Table 1).

Table 1
Geographic regions involved in Latin American collaboration in each thematic area (percentage)

AREAS	LA-LA	LA-EU	LA-USA	LA-EU-USA
Agriculture	5	36	56	3
Biomedicine	6	43	46	5
Clin. Medicine	4	28	61	7
Chemistry	6	66	25	3
Physics	7	49	33	11
Engineering	3	52	40	5
Mathematics	4	48	45	3
Total	5.4	44	44	6.6

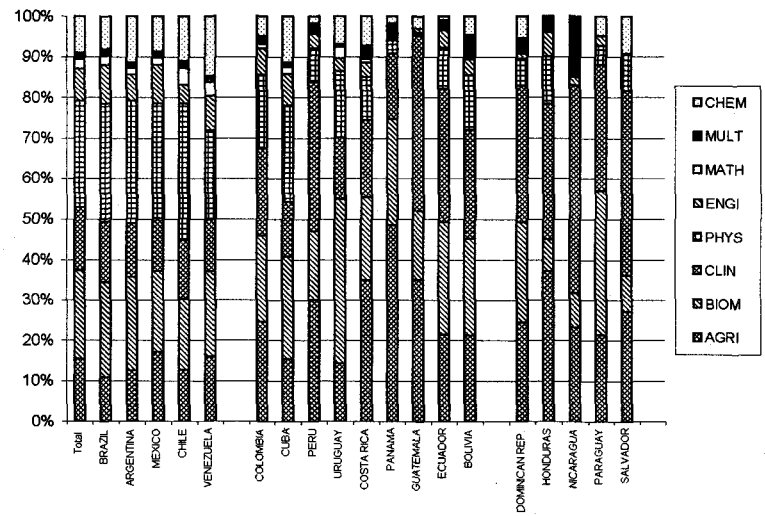

Fig. 2. Thematic areas of collaboration per Latin American country

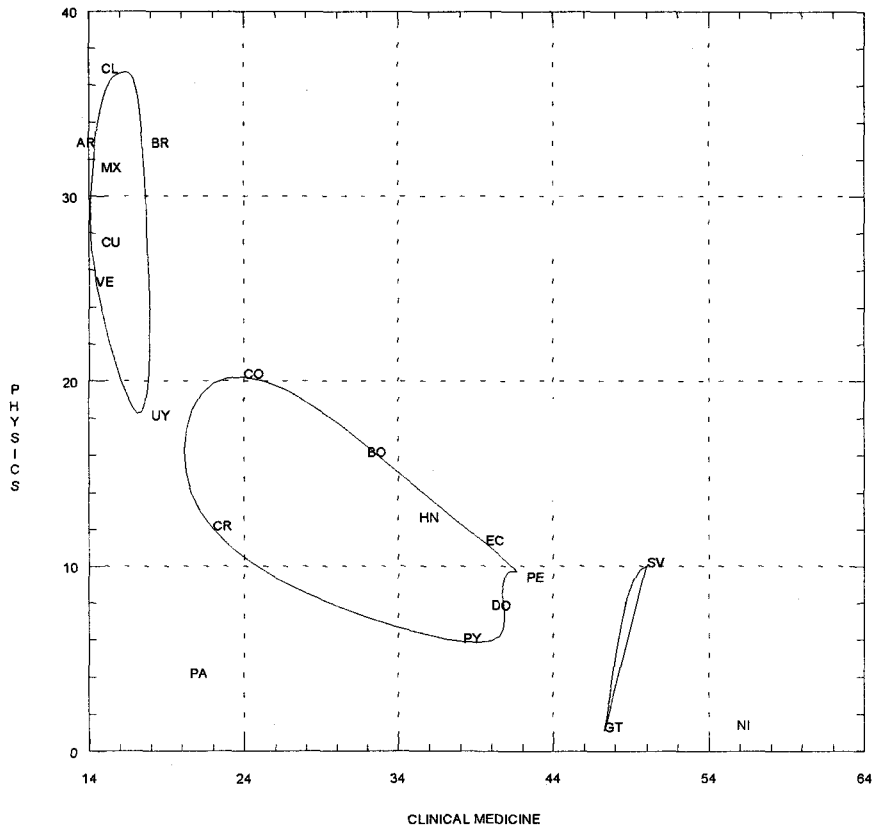

Fig. 3. Clustering of Latin American countries according to their thematic profile (Physics vs. Clinical Medicine)

The collaboration of Latin America as a whole is distributed as follows: 26% Physics, 22% Biomedicine, 15% both in Agriculture and Clinical Medicine, followed by 8% for both Engineering and Chemistry and only 2% Mathematics. When analysing the collaboration of each LA country per thematic area, we found a different pattern according to the size of the country (Fig. 2). The largest countries, Brazil, Argentina, Mexico, Chile and Venezuela, devote around 50% of their collaboration activity to technical sciences and another 50% to Life sciences. On the other hand, the smaller countries are much more Life sciences oriented (from 70% to over 90%). Only Cuba, a

middle–sized country according to its scientific output, shows a thematic pattern similar to Brazil, the largest country.

When clustering the countries according to their involvement in the different thematic areas, we obtained one cluster of these larger countries together with Cuba and Uruguay, another cluster of middle-sized countries, and the very small ones as separate points. The large countries present a high cooperation in Physics and low in Clinical Medicine and in Agriculture, while middle-sized countries have a medium activity in the different areas. Small countries present high activity in Agriculture and Clinical Medicine. In Fig. 3 we show the projection of these clusters plotted in two dimensions, those corresponding to Physics and Clinical Medicine, which were the variables that discriminate most.

The collaboration matrixes of LA countries amongst themselves, with EU countries and the USA in each thematic area were studied through cluster analysis and multidimensional scaling, in order to determine the similarities observed. Countries with less than ten documents per thematic area in the period were not considered. In Fig. 4 we show the multidimensional scaling plots of two areas: Agriculture and Chemistry. The two dimensions explain only around 44% of the variance. In Agriculture, dimension 1 is principally related to the participation of the USA (high percentage to the left), which collaborates with all countries, but particularly with those near its geographic area; while the European countries principally influence dimension 2. In Chemistry the European presence is much stronger. Dimension 1 represents high USA participation on the left and high Spanish participation on the right. Dimension 2 shows the influence of Germany and France. In general, it is easier to determine the influence of external partners than that of intra-Latin American collaboration.

Thematic area and size of the networks

The size of the networks is another differentiating factor. Considering the distribution of documents, bilateral collaboration was the most frequent (87.5%), followed by trilateral (9%) and a smaller amount of documents where from 4 to 16 of the studied countries collaborated. Network size differs per thematic area. Bilateral collaboration is predominant (over 90% of the total) in Agriculture, Chemistry, Mathematics and Engineering. Trilateral collaboration is stronger in Physics, followed by Biomedicine and Clinical Medicine; while multilateral collaboration with four or more countries involved is over 5% only in Physics and Clinical Medicine (Fig. 5).

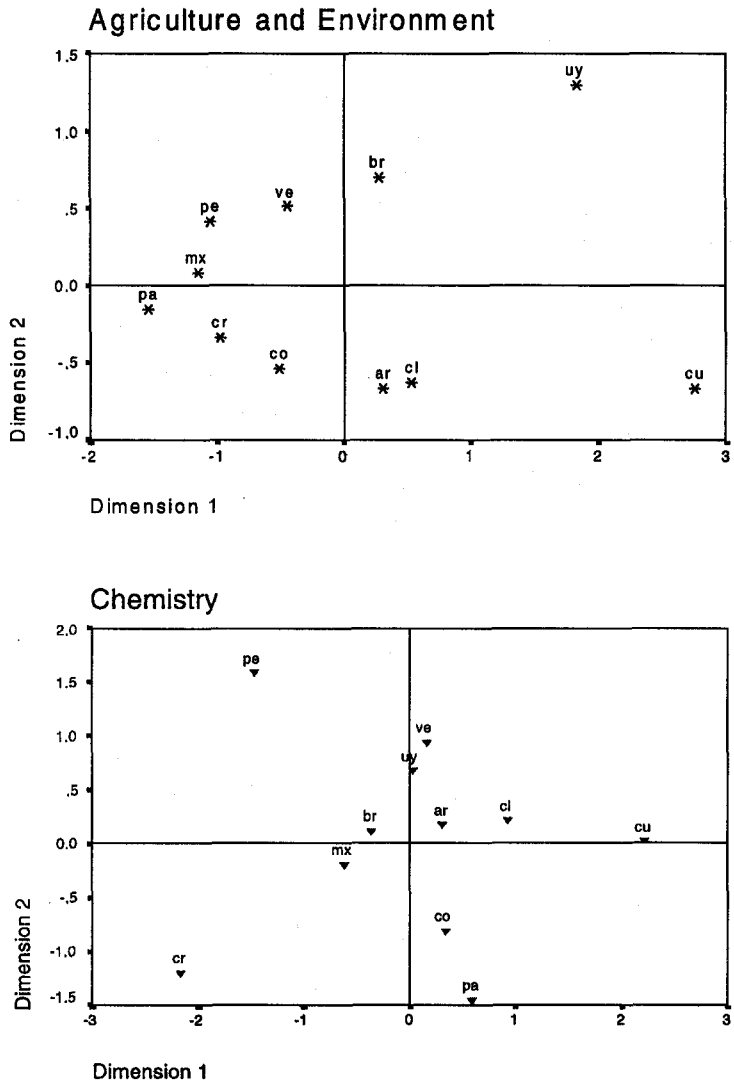

Fig. 4. Multidimensional scaling plots of LA countries' collaborations in Agriculture and Chemistry

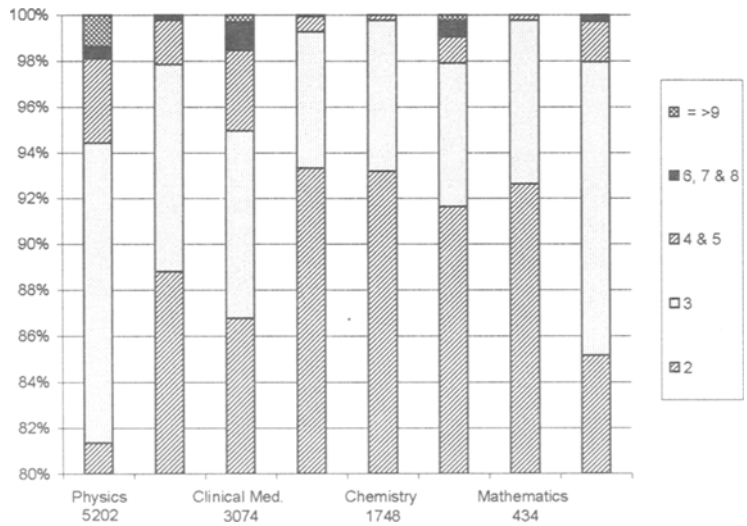

Fig. 5. Network size per thematic area

In the area of Physics, Astronomy is the most productive discipline in the 4-5 countries network (with the presence of Chile and Mexico), while Particle Physics is especially present in those documents produced by nine or more countries (where Brazil collaborates in CERN with the EU). In the area of Clinical Medicine, Medicine General & Internal is responsible for the high number of documents signed by 6-8 countries, probably due to clinical trials, where a large number of LA countries are involved.

To have a greater insight into LA countries' behaviour in the different size networks, two indexes have been calculated, I and I', to quantify the countries' participation in bilateral versus multilateral cooperation networks in each thematic area. Both indexes showed a good correlation (over 0.9), indicating that bilateral collaboration is so strong in all countries that the rest of the distribution is unclear. Index I was used to cluster the countries according to the similarity of their participation in bilateral versus multilateral networks. Table 2 shows the clusters of countries, their medians and standard deviations in each area. Smaller medians imply larger participation in multilateral collaboration networks. This is the case of cluster three, where the majority are smaller countries.

Table 2
Penetration index of Latin American countries in bilateral vs. multilateral collaboration networks (per scientific area)

AREA	Cluster 1		Cluster 2		Cluster 3	
	Median	Std.dev.	Median	Std.dev.	Median	Std.dev.
AGRICULTURE	12.9321	0.5314	7.3017	1.4576	2.1792	0.7115
	BR		AR		DO	
	CU		BO		SV	
	CL		CO		NI	
	MX		CR		PY	
	PA		EC			
			GT			
			HN			
			PE			
			UY			
			VE			
BIOMEDICINE	12.4		6.5814	0.9983	2.9077	1.6269
	PA		AR		BO	
			BR		CR	
			CO		CU	
			CL		DO	
			EC		GU	
			MX		HN	
			PY		NI	
			PE		UY	
			VE			
PHYSICS	13.0000		5.3489	1.6854	1.6897	1.0937
	CR		AR		CO	
			BO		CL	
			BR		EC	
			CU		GT	
			MX		HN	
			PE		NI	
			VE		PA	
					PY	
					UY	
ENGINEERING	14.0786	2.5122	8.2606	0.7518	2.0500	2.1095
	AR		BR		CO	
	CR		CU		SV	
	MX		CL		HN	
			EC		PA	
			VE		PE	

Table 2 *(cont.)*

AREA	Cluster 1		Cluster 2		Cluster 3	
	Median	Std.dev.	Median	Std.dev.	Median	Std.dev.
MATHEMATICS	14.7917	0.6482	7.5615	2.1229	0.0000	0.0000
	BR MX		AR CO CU CL VE		BO DO EC SV GT HN NI PA PY PE	
CLIN. MEDICINE	6.4046	0.6623	3.6016	0.5777	2.2356	0.4738
	BR GT PE		AR CL EC HN MX NI PY UY VE		BO CO CR CU DO PA	
CHEMISTRY	18.9444	2.9070	11.8636	1.2471	2.4125	1.8411
	MX UY		AR BR CU CL VE		BO CO CR DO HN NI PY PE	

In Fig. 6a we can see the different behaviour of the countries as to their participation in bilateral collaboration versus multilateral collaboration with index *I*. All countries show homogeneous patterns in Clinical Medicine, with a low index that corresponds to a strong participation in multilateral networks. A different picture is shown in Chemistry, where LA countries' behaviour shows a high dispersion, and the participation in multilateral networks is smaller.

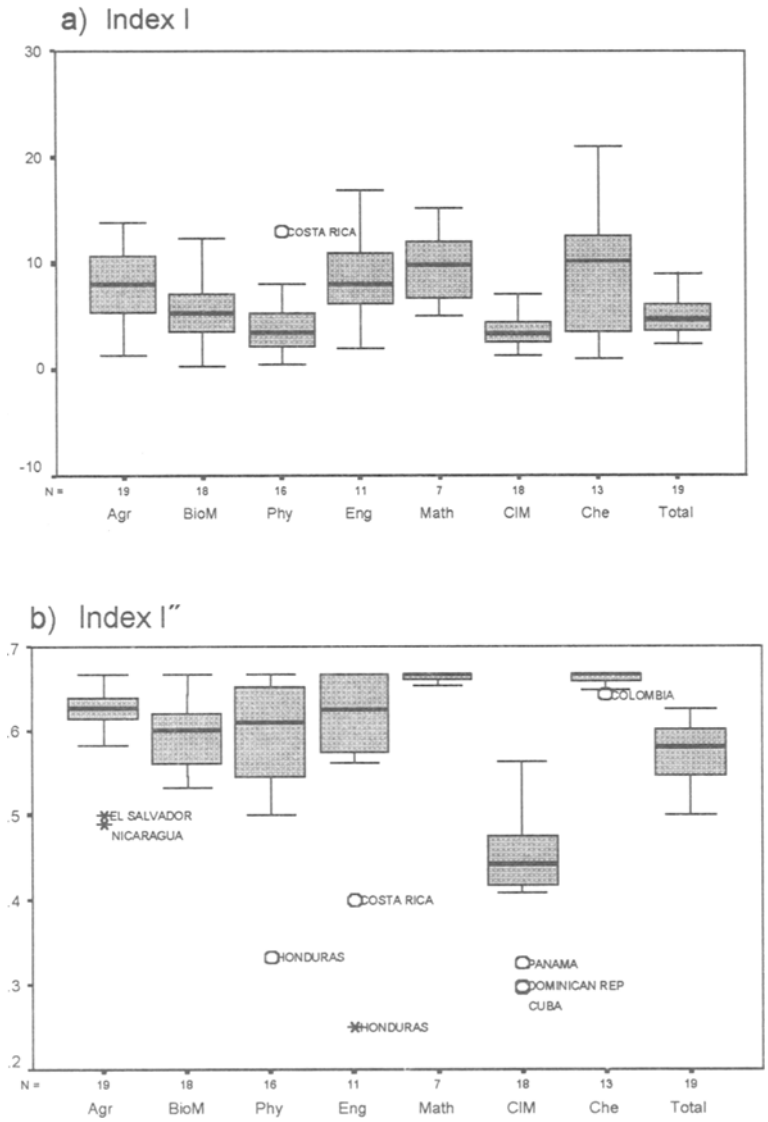

Fig. 6. Penetration indexes and dispersion of LA countries behaviour in thematic areas (6a uses index *I* while 6b uses *I''*)

In order to compare the behaviour of the thematic areas relative to the trilateral and multilateral collaboration, we introduced index I'' (Fig. 6b). The area of Clinical Medicine shows a very different pattern of behaviour from the others, with a small value of the index thus showing a large activity in the multi-lateral network, but a high dispersion of the countries behaviour. On the other hand, in Mathematics and Chemistry all countries behave similarly participating only in trilateral networks. Physics shows a high dispersion as to country behaviour, with strong participation in trilateral and also in multilateral networks. In both charts outlier countries can be observed.

Evolution of the different networks

When comparing the total scientific production of LA countries at the beginning and at the end of the studied period, we observe a 51% increase rate. The same relation for cooperative papers shows a 66% increase (*Fernández* et al., 1998), that is to say international collaboration grows at a higher rate than Latin American countries output. But taking into account the size of the network, we can observe that while bilateral collaboration shows a 59% increase rate, when three countries are involved the rate increases to 124%, and is even higher (up to 133%) for multilateral collaboration networks (Table 3). Multi-country networks where three or more countries are involved grow at a much quicker rate than bilateral collaboration. This evolution differs per thematic area, as shown in Table 3.

Table 3
Increase of LA collaboration (1991 to 1995) per network size and thematic area (percentages)

AREA	2 countries	3 countries	≥4 countries	Global increase
Agriculture & Environment	38.5	152.2	400.0	45.0
Biomedicine	61.4	288.9	136.4	75.5
Chemistry	75.7	70.0	-50.0	74.3
Clinical Medicine	62.9	94.9	69.6	65.9
Engineering & Technology	85.5	118.8	0.0	85.6
Mathematics	20.5	166.7	-	26.7
Physics	63.1	96.9	157.6	71.2
Total	59.4	122.4	133.3	66.0

Multi-regional collaboration

A particular case of the multilateral network is that in which all three geographic regions participate simultaneously: LA, EU and USA. A total of 1152 documents fulfil these conditions. They represent 6.6% of the whole LA collaboration and their rate of increase is the highest (154%). In 1068 of those documents only one Latin American country participates, two LA countries in 59 documents and only in five documents do five or more LA countries collaborate.

Figure 7 shows the activity index per thematic area as compared to the total LA collaboration. A clear focus towards Physics appears, related to the predominant fields: Astronomy & Astrophysics, followed by Physics, General, Nuclear, Particles & Fields, Condensed Matter. The next most productive fields are Genetics, Biochemistry, Medicine General & Internal, Neuroscience, Pharmacology, Microbiology and Cancer, all of them in the Biomedicine and Clinical Medicine areas. On the contrary, in Agriculture the proportion of documents with the three geographic regions is low (USA being the main partner) and also in Chemistry, Engineering and Mathematics (where EU was the main partner). The four most active LA countries change their relative positions: Brazil and Mexico come first, followed by Chile, and then Argentina.

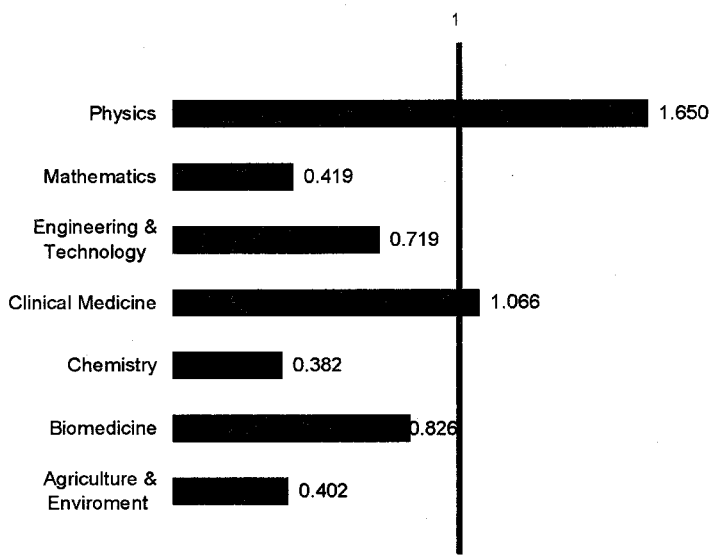

Fig. 7 Activity index per thematic area of the multi-regional network

Another question to be taken into account is that in this paper we have focused on the networks amongst LA countries, and also with the USA and the EU. However, other countries also participate highly in these networks, although their whole collaboration output was not studied here.

Discussion

Bibliometric indicators proved to be a useful tool in identifying both formal and informal scientific cooperation of LA countries (*Fernández* et al., 1992). The increase observed in the number of internationally co-authored papers demonstrates the importance of international cooperation. Besides, the strong increase of multilateral co-publications reveals the relevant role of the research networks in promoting multiple interactions, technology and know-how transfer and common activities. The bibliometric approach shows data about the structure and nature of the network and trends in its evolution. In fact, the analysis of co-publications with three or more countries can be used as an approach to analyse international scientific research networks.

The collaboration patterns of LA countries are not homogeneous and depend on a number of factors. As already described (*Luukkonnen* et al., 1992) the size of the country is inversely related to its international collaboration rate. In our data small countries show 60-74% collaboration rates, while these rates are only 23-40% for larger countries. In addition, the size of the countries is also related to their participation in bilateral collaboration (around 85-87% in larger countries) or multilateral networks, in which middle-sized and small countries are more strongly involved (up to 29%). This can be related to the topics per se, or to a higher possibility of small countries participating in international research through large projects in which other LA countries are already participating. The more attractive thematic areas for small countries are those related to Life Sciences (up to 90% of their output) the USA being their principal partner. Large countries are more active in technical areas, with the EU as their principal partner. This could be partly due to a larger activity of the USA in SCI covered Life Sciences, and conversely to a larger activity of Europe in technical areas.

Although the majority of collaboration papers are bilateral ones (87.5%), it is interesting to analyse the larger networks through the indexes I and I''. Their weight varies per thematic area. In Agriculture and Chemistry collaboration between two or three partners is the most frequent (high I and high I''), presumably in topics of local interest. Larger networks are involved in Physics and Clinical Medicine. In Physics trilateral collaboration is very strong (low I and high I''), while collaboration of four or

more countries is particularly strong in Clinical Medicine (low *I* and low *I'*). This is partly related to Big Science facilities and clinical trials where a large number of countries and interests are involved.

The increase of multilateral co-publications probably indicates the impact of multilateral programmes fostering international collaborative research involving LA countries, the EU and the USA (*Sebastián*, 1992; *Arvanitis* et al., 1995). Bilateral and multilateral collaboration have different characteristics and respond to different modalities and thematic priorities established by promoting agencies and programmes. However, the bibliometric approach detects the existence of an important amount of cooperation not easily identified with formalised international programmes, as is the case of joint collaborations between research groups of LA, EU and USA. The origin and development of collaborations involving these three regions is probably related to the "invisible colleges" fostered by the international mobility of researchers and the increasing importance of research networks as an instrument to influence the way in which scientific knowledge is being produced. The triangular collaboration is particularly important in Physics, partly based on Big Science facilities, such as CERN, ESA or Astronomic Observatories.

The study of intra-Latin American networks requires the use of other sources to complement the limited information on national publications provided by SCI database. Regional databases would be the best option, but at present the biomedical database BIREME only registers one address and PERIODICA has a limited coverage of LA journals (*Narvaez-Berthelemot* et al., 1998).

In order to have a better insight into the Latin American picture, we have started to study the case of Brazil, the most active LA country as regards scientific publications in SCI. In particular, we are interested in relating the scientific output of Brazil to its participation in a number of formalised international cooperative programmes. Some of these are fostered by the EU, as STD and INCO in Framework Programmes III and IV and ALFA (devoted to Latin American Academic networks) as well as by the Programme CYTED (Iberoamerican Programme for Science & Technology for Development). Brazilian participation in CERN activities was also taken into account (*Sebastián* et al., 1998).

*

We want to thank Laura *Barrios* for her help in the statistical treatment of data. This research was partly financed by the Agencia Española de Cooperación Iberoamericana.

References

ARVANITIS, R., GAILLARD, J., CHATELIN, Y., MEYER, J.B., SCHLEMMER, B., WAAST, R. (1995) El impacto de los fondos europeos de apoyo a la cooperación científica con países en desarrollo, *Interciencia*, 20 (2), 76-82.

FERNÁNDEZ, M.T., AGIS, A., MARTÍN, A., CABRERO, A., GÓMEZ, I. (1992) Cooperative research projects between the Spanish National Research Council and Latin-American institutions, *Scientometrics*, 23 (1), 137-148.

FERNÁNDEZ, M.T., GÓMEZ, I., SEBASTIÁN, J. (1998) La cooperación científica de los países de América Latina a través de indicadores bibliométricos, *Interciencia*, 23 (6), 328-337.

GALBÁN, C., GÓMEZ, I. (1992) La cooperación científica entre España e Iberoamérica en revistas internacionales, *Revista Española de Documentación Científica*, 15 (4), 405-415.

KRAUSKOPF, M., VERA, M.I. (1995) Las revistas latinoamericanas de corriente principal: indicadores y estrategias para su consolidación, *Interciencia*, 20 (3), 144-148.

LEWISON, G., FAWCETT-JONES, A., KESSLER, C. (1993) Latin American scientific output 1986-91 and international co-authorship patterns, *Scientometrics*, 27 (3), 317-336.

LUUKKONEN, T., PERSSON, O., SIVERSTEN, G. (1992) An outline for understanding patterns of international scientific collaboration, *Science, Technology and Human Values*, 17, 101-126.

NARVAEZ-BERTHELEMOT, N., FRIGOLETTO, L.P., MIQUEL, J.F. (1992) International scientific collaboration in Latin America, *Scientometrics*, 24 (3), 373-392.

NARVAEZ-BERTHELEMOT, N., RUSSELL, J.M., VELHO, L. (1998) The scientific collaboration of the Mercosur countries as an indicator of Latin-American regional activity, In: *Fifth International Conference on Science and Technology Indicators*, Hinxton, Cambridge, UK.

SANCHO, R., CABRERO, A., DELGADO, F., FERNÁNDEZ, M.T. (1994) A study of scientific co-operation between South, Central American and Caribbean countries, In: *New Worlds in Information and Documentation*, J.R.P. ALVAREZ-OSSORIO and B.G. GOEDEGEBUURE (Eds.) Elsevier, The Netherlands.

SEBASTIÁN, J. (1992) The CYTED Programme: an innovative venture for international cooperation in Ibero-America, *Impact of Science on Society*. UNESCO. Paris, 167, 215-224.

SEBASTIÁN, J., FERNÁNDEZ, M.T., GÓMEZ, I. (1998) Participación de Brasil en Redes Internacionales de Investigación, *Proceedings of the XX Simpósio de Gestâo da Inovaçâo Tecnológica,* PACTO Sao Paulo, Brazil, 902-912.

URDÍN, M.C., MARTÍN, M.J. (1992) La cooperación científica entre España e Iberoamérica en revistas españolas, *Revista Española de Documentación Científica*, 15 (4), 416-424.