Scientometrics (2012) 93:699–717
DOI 10.1007/s11192-012-0794-6

Blockmodeling of co-authorship networks in library and information science in Argentina: a case study

Zaida Chinchilla-Rodríguez · Anuska Ferligoj · Sandra Miguel · Luka Kronegger · Félix de Moya-Anegón

Received: 30 September 2011 / Published online: 26 June 2012

Abstract The paper introduces the use of blockmodeling in the micro-level study of the internal structure of co-authorship networks over time. Variations in scientific productivity and researcher or research group visibility were determined by observing authors' role in the core-periphery structure and crossing this information with bibliometric data. Three techniques were applied to represent the structure of collaborative science: (1) the blockmodeling; (2) the Kamada-Kawai algorithm based on the similarities in co-authorships present in the documents analysed; (3) bibliometrics to determine output volume, impact and degree of collaboration from the bibliographic data drawn from publications. The goal was to determine the extent to which the use of these two complementary approaches, in conjunction with bibliometric data, provides greater insight into the structure and characteristics of a given field of scientific endeavour. The paper describes certain features of Pajek software and how it can be used to study research group composition, structure and dynamics. The approach combines bibliometric and social network analysis to explore scientific collaboration networks and monitor individual and group

Z. Chinchilla-Rodríguez (✉) · F. de Moya-Anegón
Consejo Superior de Investigaciones Científicas, Centro de Ciencias Humanas y Sociales,
Instituto de Políticas y Bienes Públicos, C/Albasanz, 26-28, 28037 Madrid, Spain
e-mail: zaida.chinchilla@csic.es

F. de Moya-Anegón
e-mail: felix.demoya@csic.es

Z. Chinchilla-Rodríguez · S. Miguel · F. de Moya-Anegón
SCImago Research Group, Ljubljana, Slovenia
e-mail: sandra@fcnym.unlp.edu.ar

A. Ferligoj · L. Kronegger
Faculty of Social Sciences, University of Ljubljana, Kardeljeva ploscad 5, 1000 Ljubljana, Slovenia
e-mail: anuska.ferligoj@fdv.uni-lj.si

L. Kronegger
e-mail: luka.kronegger@fdv.uni-lj.si

S. Miguel
Departamento de Bibliotecología, Facultad de Humanidades y Ciencias de la Educación, Universidad Nacional de La Plata, 48 e/6 y 7. 5to piso, La Plata, Argentina

careers from new perspectives. Its application on a small-scale case study is intended as an example and can be used in other disciplines. It may be very useful for the appraisal of scientific developments.

Keywords Scientific collaboration · Bibliometrics · Blockmodeling · Social network analysis

Introduction

Scientific collaboration is one of the most obvious features of the production of scientific knowledge (Price 1963). All empirically contrasted advantages are associated with this type of partnering, on both the macro and the micro analysis level (Katz and Martin 1997; Beaver 2001; Persson et al. 2004; Bozeman and Lee 2005; Bartneck and Hu 2010; Chinchilla-Rodríguez et al. 2010). Strong and persuasive philosophical or scientometric arguments can be put forward in support of collaborative research and its greater epistemic authority than study conducted by individual researchers (Beaver 2004).

Wagner and Leydesdorff (2005) analysed the growth in international collaboration in science under the premise that collaboration is an emerging, self-organising system in which the selection of a partner and the place where research is conducted depend not on national or institutional incentives or constraints, but on the researcher's choice. They pointed out that scientists collaborate with each other to gain visibility, to exploit synergies or to rationalise resources. Their working hypothesis was that "preferential attachment" is related more closely to an intellectual and a social organisation than to any other factor.

The idea of focusing the analysis on an actor's position and role within a network is related to the methodological proposal put forward in this paper. The present approach combines bibliometric information on scientific activity with the type of information used to determine individual's position in a social hierarchy by studying its core-periphery structure.

A core-periphery model can be adopted to determine network structure in any discipline (Ferligoj and Kronegger 2009; Kronegger et al. 2012). Core-periphery structure is characterised by a very uneven distribution of ties, short distances between nodes and high clustering (Borgatti and Everett 1999). Newman (2004a, b) reported that the degree-distribution of nodes shows a tendency for a small proportion of scientists to effectively attract a large number of collaborators, with much inequality among actors. Most of an individual's ties to the other researchers short-cut through his collaborators' best-connected. This would explain why scientific collaboration networks entail a core-periphery structure in which a group of authors (the core) is densely inter-connected and a complementary set of (peripheral) nodes that are not connected between themselves but can be connected to the members of the core. Exploring poorly understood networks can reveal how scientists interact and generate the intrinsic structure of scientific collaboration (Ferligoj et al. 2011; Kronegger et al. 2011).

Three distinct collaborative structures have been identified in sociology (Moody 2004). One is the *small-world model* defined by Watts and Strogatz (1998). The main characteristic of this collaborative structure is a high level of local clustering and a small average number of steps between actors.

In the *scale-free model,* prominent scientists constitute hubs that connect the network. Barabási and Albert (1999, 2002) proposed formal model that has been widely accepted to find the structure of scientific collaboration networks. This model is based on the idea of the cumulative advantage gained from preferential attachment (the Matthew effect): scientists whose publications have afforded them visibility in their field are preferred as co-authors. It is, moreover, consistent with a process that Moody (2004) called "star production", in which highly reputed authors with many collaborators attract more attention and connections from authors joining the network than the others. This suggests that their disappearance from the network would have a dramatic impact on the network.

The third model envisages a collaborative structure in which ties are distributed evenly across an entire disciplinary network. Some previous social network analyses have shown that co-authorship ties inside the disciplines are not necessarily socially cohesive. In these structures, some of the collaborative groups, which vary in size, are interconnected, while others are completely isolated (Newman 2001, 2004a, b). These structures were analysed by Mali et al. (2010) using a combined approach to define co-authorship patterns in Slovenian sociology. They focused on bibliometric networks adopting a blockmodeling approach to establish individuals' positions in networks. For Mali et al. the effect of external factors on activity and its assessment is mediated by R&D policy; therefore, to understand partnering patterns, the role of external factors must be viewed against a broader interpretative backdrop. National R&D policy is expected to deliver an R&D assessment system that encourages scientists to internationalise and enhance their results by merging domestic and foreign scientific endeavour. Based on the small-world approach, Mali et al. attempted to ascertain whether this structure encourages Slovenian sociologists to or discourages them from internationalising their publishing efforts. They empirically tested whether an increase in the number of co-authored publications led to publish fewer papers in international peer-reviewed journals than the sociologists outside this small world structure.

More recently, Kronegger et al. (2012) adopted two approaches to network dynamics modelling. One was based on the small world model and the preferential attachment mechanism. The other focused on cumulative advantage, taking the behaviour of individual actors in a network into consideration. They combined the two approaches to study the structure and dynamics of scientific collaboration networks in four subject areas.

Building on these studies, the present research focuses on dynamic co-authorship networks in the specific field of information science in a Latin American country from 2001 to 2009. The blockmodeling approach is used for a micro-level exploration of the structure of these collaboration networks. The aim of the study is to determine whether this approach is appropriate one for micro-level analysis of the internal structure of co-authorship networks over time. It is applied on a case study of research practice in the Department of Information Science at the National University of La Plata, Argentina. Combining the obtained researcher's position in the core-periphery structure with the bibliometric data provides insight into the dynamics of the researcher's and research group's scientific productivity and visibility.

Hypothesis and objectives

The main hypothesis is that there exist several groups of authors that are strongly connected (cores) in the co-authorship network of a scientific field. These authors publish less in international journals than authors outside the cores. Moreover, such cores do not encourage researcher mobility.

The goal of the study is to identify core-periphery structures and their scientific output (1) to review the evaluation methods for research group appraisal, promotion and funding applied by the respective agencies; (2) to detect institutional policy-induced publication and collaboration patterns; and (3) to revise research staff training and promote mobility.

Following the research by Miguel et al. (in press), this paper contributes to the study of research group composition, structure and dynamics by combining bibliometric analysis and social network analysis to establish new perspectives for analysing scientific collaboration networks and monitoring individual and group careers.

Data and methods

The methodology combines three approaches. Two techniques were used to study the structure of collaboration networks: (1) the blockmodeling and (2) the Kamada-Kawai algorithm, based on the similarities in co-authorships present in the analysed documents. The third approach is used to obtain the production and the collaboration patterns from bibliometric data. The goal was to determine whether and to what extent the use of two network approaches combined by the bibliometric data, provides greater insight into the structure and characteristics of a given field of scientific endeavour.

Data source

The data source used in this study was the corpus of curricula vitae (CV) and the bibliographies of the teaching staff at the Faculty of Humanities and Education Science's Department of Library Science (DHUBI) at National University of La Plata, Argentina, and the information on their research partners in the projects and the publications in the period 2001–2009. The choice of the source is justified by the fact that the CVs represent researchers' academic career and output, and must be submitted when asking for the funds for new projects (Cañibano and Bozeman 2009).

Data gathering and processing

The researchers' project and publication data for 2001–2009 obtained from their CVs and bibliographies were uploaded into a relational database (formulated ad hoc). Despite the efforts to standardise CV format (Onofrio 2009) in Argentina, quality control had to be done on the data due to the lack of information or because of inconsistency in the information.

As not all the CVs had the total number of participants in each project, the institutional records on research projects had to be considered to complete the data. In addition, data entry formats showing researchers' full names, both for projects and publications, had to be standardised. In all, 146 publications (52 journal articles and 94 published papers in the conference proceedings) and 77 authors were included in the database. Both singly and jointly authored papers were included, with the mean value of co-authors of 2.4. 60 % of the papers involved collaboration.

Only journal articles and papers in the conference proceedings, the type of papers showing the highest visibility, were considered. These two types of publications accounted for 85 % of total area output in Argentina (Miguel 2009), a figure similar to the one reported for other countries (Shaw and Vaughan 2008). This study addresses research only, excluding other areas of activity such as education or public activities which have been analysed by other authors (Braam and van den Besselaar 2010).

The data were collected and standardised. Each author (actor) was associated with the identifier for the project or publication in which he/she was involved. Data on institutional affiliation, professional category, subject area and academic position within the department were included for intra-relations, along with institutional affiliation and disciplinary profile for inter-relations. In total, six mutually exclusive categories were established: (1) DHUBI researcher (R-DHUBI); (2) DHUBI graduate or undergraduate student (UGS-DHUBI); (3) researchers from other domestic institutions (LIS-ROIC); (4) researchers from foreign institutions (LIS-RFI); (5) researchers from other disciplines working out of Argentinean institutions (ODAIR), and (6) researchers in other disciplines working out of foreign institutions (ODFIR). These arbitrary categorises were based on an ad hoc classification to detect professional category (1 and 2), intra-institutional collaboration (1 and 2), national and international collaboration (3, 4, 5 and 6) and interdisciplinarity (5 and 6).

Data generation

The frequency of each actor's participation in the co-authorship of publications was calculated from the collected data. Then symmetric matrices were generated in which both rows and columns have researchers' names. As in the other studies (Perianes-Rodriguez et al. 2009), absolute values were used for co-occurrence frequencies and the values on the main diagonals were eliminated. Some authors argue that normalising frequencies distorts the distribution of information and that raw data are a valid and sufficient basis for calculating the distances between authors (White 2003; Leydesdorff and Vaughan 2006). The data and resulting matrices were obtained for three time spans (2001–2003, 2004–2006, and 2007–2009) to visualize variations in co-participation over time as was proposed in previous studies (Borner et al. 2005).

Blockmodeling

Although bibliometric studies have studied scientific collaboration patterns for some time (Sonnenwald 2007) using social network analysis (SNA), aspects such as clustering of actors and its dynamics could be appropriately studied to better reflect the social nature of science. Generalised blockmodeling was developed to determine positions (clusters of actors) and role systems (networks of positions). As scientists can be reasonably viewed as playing roles within their respective fields, identifying structures in the network is one way of determining how scientists collaborate. Blockmodeling enables to delineate to the intrinsic structure of science (Ferligoj et al. 2011).

Following the small-world structure of co-authorship in the DHUBI, *blockmodeling* was used (Doreian et al. 2005; Kronegger et al. 2011). In the paper of Kronegger et al. a core is defined as a set of scientists, that all collaborate with each other. In blockmodeling terms, a *core* position determines a complete diagonal block. The overall structure may contain several cores. If the members of each core co-author only with other members of their own core, all the cores are of the same type. A core whose members also systematically partner with members of other cores is called a *bridging core*. The *semi-periphery* consists of scientists partnering with at least one scientist within their scientific field but in a fashion that differs substantially from core members' modus operandi. Some members of the semi-periphery may also co-author papers with scientists in cores, but these ties are sporadic and follow no systematic pattern. Finally, scientists who do not collaborate with any other scientist in their field are located in the *periphery*.

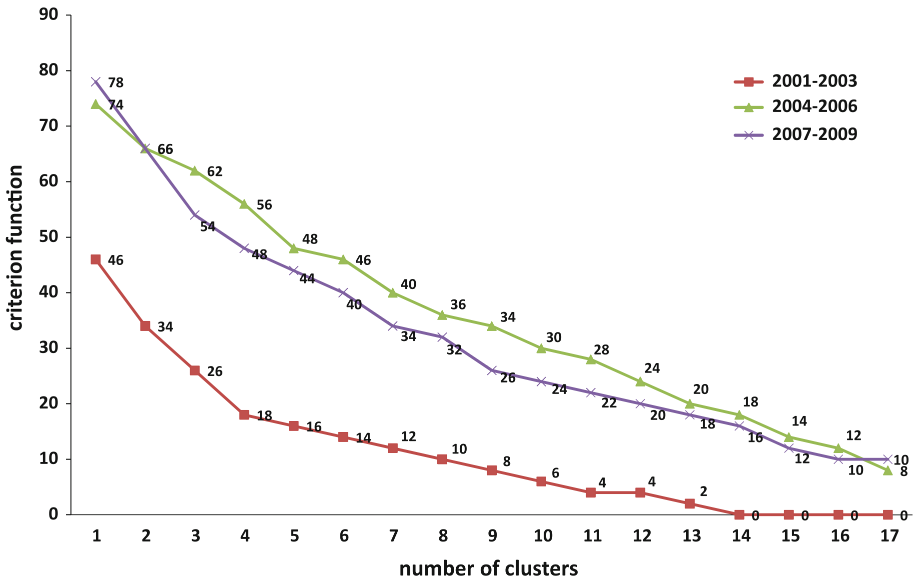

Fig. 1 Criterion function for each obtained partition and each period

Clusters of scientists are also called positions. Structural equivalence was used to determine the core-periphery structure as pre-specified blockmodel, and partitions into two to eleven positions were examined. The standard blockmodel display was used, i.e., a square array in which the rows and columns in the relational matrix have been permuted to group the actors of each cluster. The clusters were numbered and separated by blue lines. The numbers were assigned to the authors to preserve their anonymity.

The best blockmodel was chosen by calculating the percentage of inconsistencies (criterion function) for each obtained partition. The number of inconsistencies tends to decline with increasing number of clusters in the case of structural equivalence. The number of actors in each period must be taken into account to calculate the criterion function. In our case, we have chosen eight partitions for the period 2001–2003, and eleven for the periods 2004–2006 and 2007–2009. Prior information from interviews (Miguel et al. in press) also helped to define the best partition. Figure 1 gives the values of the criterion function for each period.

Software

All the analyses were performed by using Pajek, open software for the analyses and the visualisation of large networks (Batagelj and Mrvar 2003) available for non-commercial use (http://pajek.imfm.si).

Results and discussion

The co-authorship network structure in DHUBI and researchers' positions in that structure in 2001–2003 determined by blockmodeling are shown in Fig. 2a. Seven clusters can be clearly distinguished (numbered and divided by lines) in the core-periphery structure: the

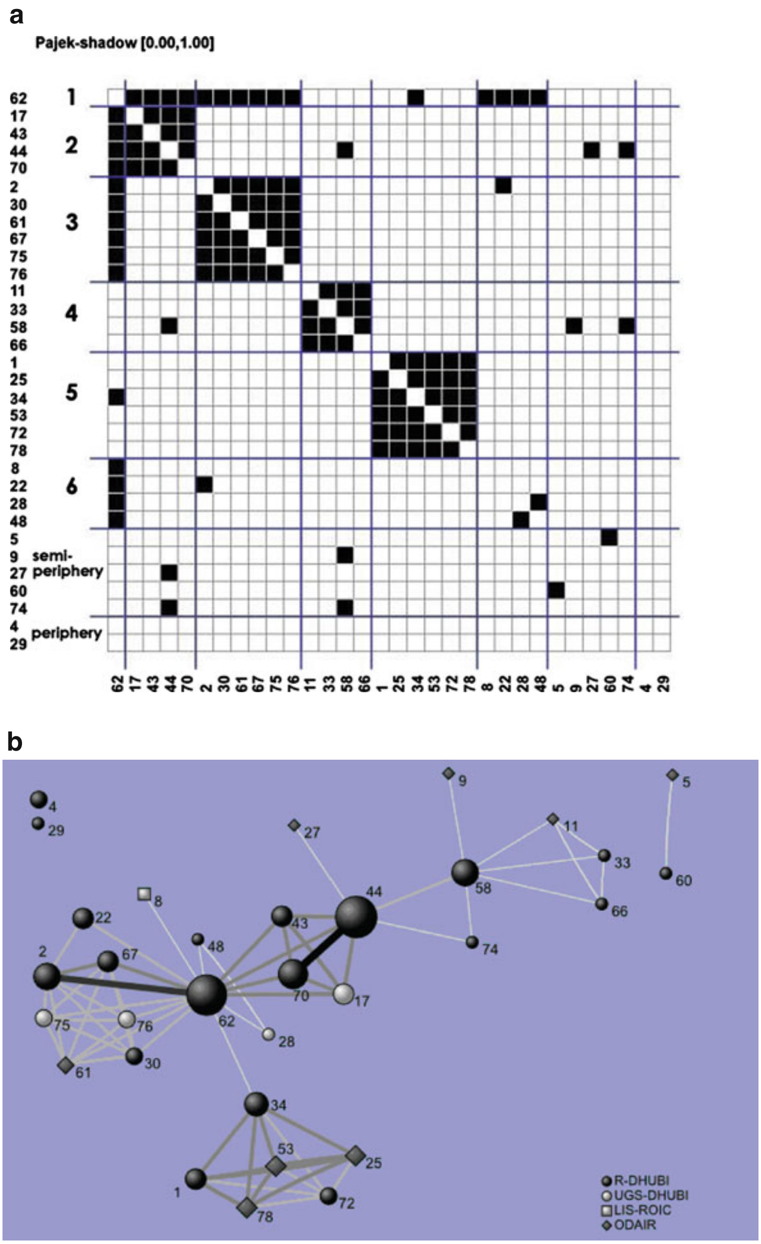

Fig. 2 Dynamics of evolving networks. Evolution of the DHUBI blockmodel structure: **a** blockmodel structure and **b** co-authorship network, 2001–2003

first bridging core, four simple cores (the authors in each of these cores collaborate only with each other), a large semi-peripheral cluster (the authors in this cluster do not systematically collaborate with the other authors) and the peripherial cluster (these two researchers do not collaborate with any other researcher).

From the top to the bottom, the first core is situated at the top left, and contains a bridging researcher. This individual is the head of the department and collaborates with all the authors from the clusters 2 and 3 and some peripheral authors, but not with the authors from the cluster 4. This can be seen as a "scale-free model", in which a prominent scientist is responsible for connecting the network. The key role is played by the author 62, who attracts co-authorship from outside of the department and is often chosen as a co-author by others. This is known as "cumulative advantage" or the "Matthew effect", and is based on the principle of preferential attachment. Such ties might be traced to the student-professor relationship, while the explanation for their appearance in several clusters could be the difference in the subject matter of the papers published.

Four authors are in the second cluster. Unlike the other three, the author 44 collaborates with other authors besides the department head. The third cluster contains six authors. Both these clusters are very cohesive. All authors work together as well as with the head of the department (cluster 1), while author 2 also partners with an author from the semi-periphery cluster. The fourth and fifth clusters exhibit essentially the same structure: a small-world model in which one author (58) partners with at least one semi-peripheral author, who may engage in another discipline, as in the case of the author 9. In this type of highly cohesive model just a few steps are enough to connect all the participants.

The cluster 6, contains four researchers who collaborate with the author 62. The semi-peripheral cluster contains five authors that do not systematically collaborate with the other authors. In the cluster 8, in the periphery, two authors not involved in co-authorship are located.

The members of the cores, closest to the small world model, form cliques which were detected in an earlier study (Miguel et al. in press). One significant difference is that the authors who collaborated with only some of the members of the cores were classified here into the semi-periphery. The actors with no inter-relations are in the peripheral cluster. This may seem confusing, since intuitively clusters would appear to collect actors with something in common, such as co-authorship. In some cases, however, the common characteristic is just the opposite: non-relationship.

The number of authors and clusters as well as network density was larger in 2004–2006 than in the previous period. The major difference, however, was that the author 62, while still a key figure in the department, shared that position with another author (67) in the first cluster. Bridging authors working in the department as researchers (48 and 68) and one student (13) also appeared in this period. Another difference with respect to the previous period was the size of the semi-periphery and the heterogeneity of its researchers, who were from abroad or from other disciplines. The dynamic nature of the structure and authors' changing roles are clearly illustrated in Fig. 3.

The most prominent difference in the last period (2007–2009) was the presence of two bridging authors (48 and 58), and two pairs of authors who also co-authored with the rest of the network (30, 67) and (2, 62). These are the leading actors in terms of cohesion. In addition, this period was characterised by two components whose research trends differed considerably. The respective alliances suggested they were consolidated and their research activity had reached a certain degree of maturity, an impression obtained by the interviews held with the experts.

The first component on the right in Fig. 4b includes the first three clusters. The second component contains the following four clusters and the semi-periphery with some authors which are linked to both components. The first component contains a very cohesive first cluster in which students participates alongside department researchers. The highest productivity was attained by the author 44, who partnered with an author from another

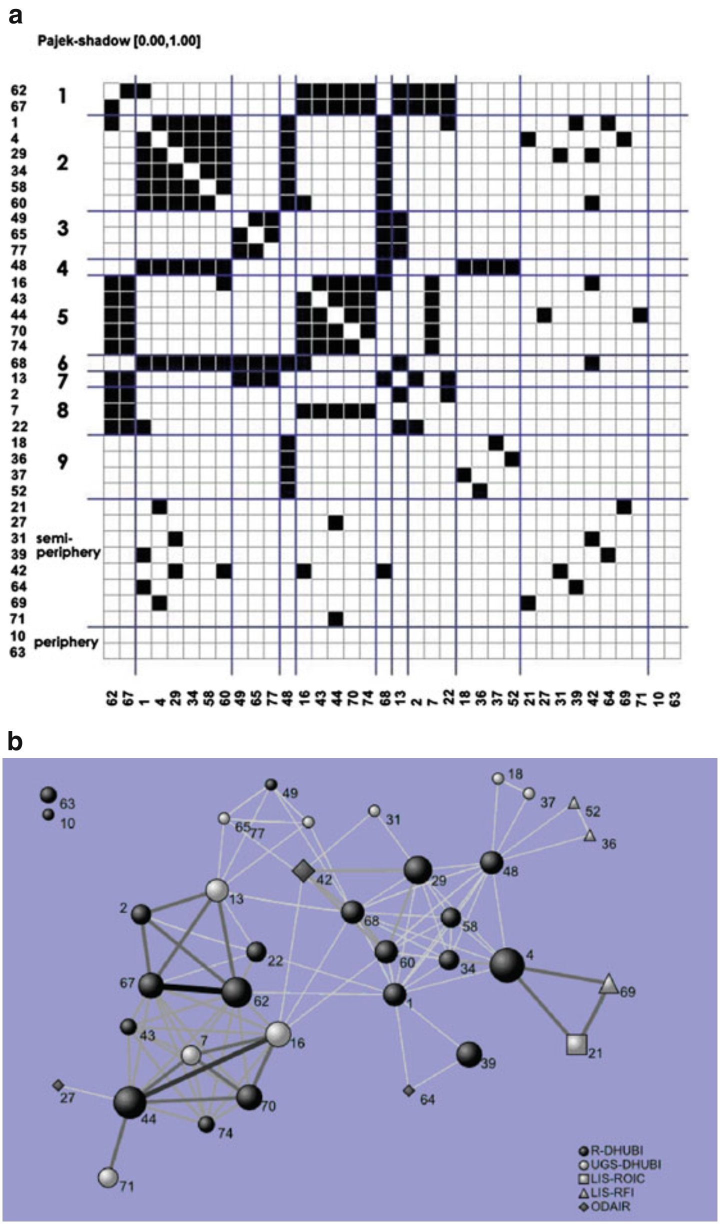

Fig. 3 Dynamics of evolving networks. Evolution of the DHUBI blockmodel structure: **a** blockmodel structure and **b** co-authorship network, 2004–2006

discipline (27) positioned in the semi-periphery. Two pairs of authors hold the key positions in the first component: (30, 67 from the second cluster) and (2, 62 from the third cluster). In fact, the author 62 continued to play a bridging role, together with another actor (2), who served as a bridge between the first cluster and fourth cluster, while also authoring with an actor from another discipline.

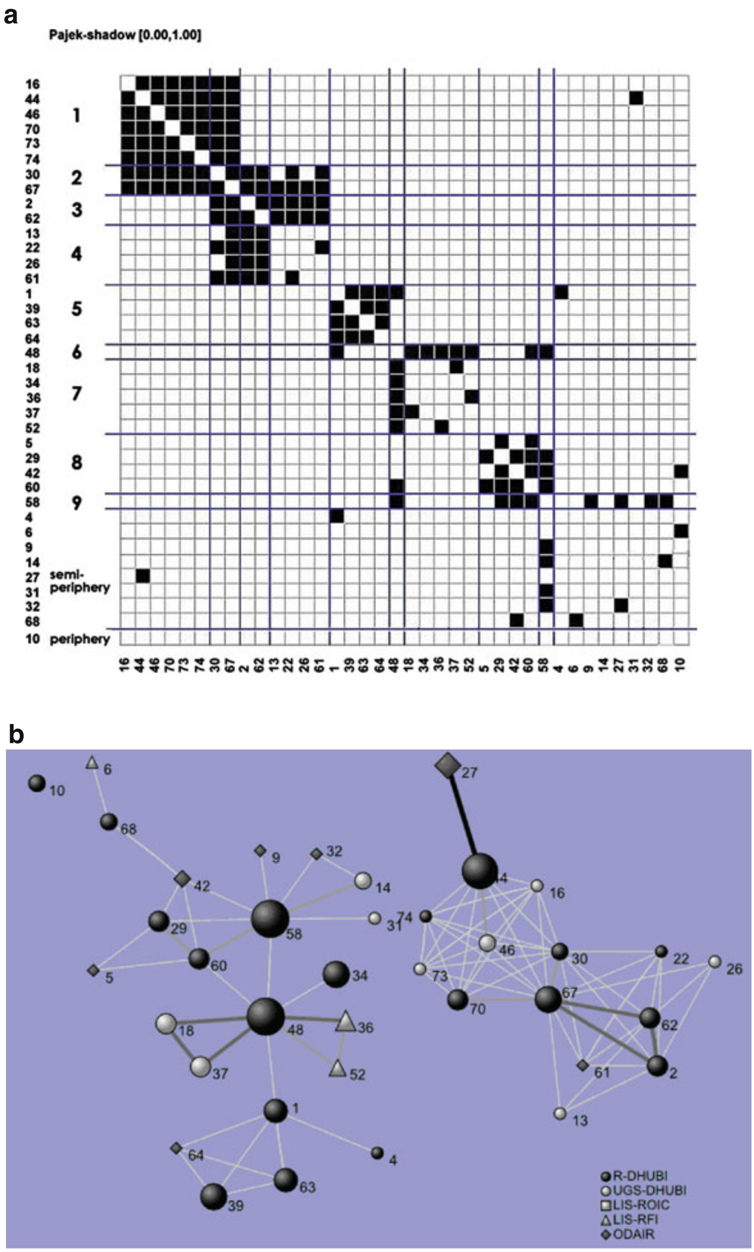

Fig. 4 Dynamics of evolving networks. Evolution of the DHUBI blockmodel structure: **a** blockmodel structure and **b** co-authorship network, 2007–2009

In the second component (on the left), very cohesive cluster 5 consists of four authors. The author 1 is the bridge to the authors 4 and 48 from the cluster 5. The author 48 also plays a key role, collaborating with all the authors from the cluster 7 and the cluster 8. The authors 48 and 58 are significant players, since both contribute to the network cohesiveness: while the actor 58 exhibited greater interdisciplinarity, the actor 48 had contacts with other institutions, one domestic and one foreign.

The cluster 10, the semi-periphery, contained authors who nonsystematically collaborated only with a few authors. Surprisingly, the author 68, a bridging one in the second period, occupies a semi-peripheral position in the third period. To use the term proposed by Price and Gürsey, he can be called as a "terminator" author.

The scenario in the last period is very different from the initial one, where the semi-periphery is much larger and more heterogeneous. None of the groups is isolated in 2007–2009, and all tended to collaborate. The presence of bridging authors is perfectly visible. Less clear, however, is the type of structure: the small-world and scale-free models are diffuse, relationships run across the entire network, only a few groups varied in size, and the main actors are connected to students and researchers from other disciplines or other national or international institutions. What was expected was a simple core-periphery structure with multiple simple cores, a semi-periphery and a periphery. However, in all three periods studied, the most frequent blockmodel was a core-periphery structure with bridging cores that tended to be smaller than the cores they bridged. These results are consistent with the findings reported by Kronegger et al. (2011), who studied four scientific disciplines in four time intervals. They found core-periphery structures with bridging cores for biotechnology, for physics in the first period and for mathematics in the second. They used the term "consolidated cores" to describe the existence of both simple and bridging cores, which seems structurally important because it heightens the coherence of the disciplinary core and facilitates the exchange of ideas across small specialty cores.

These structures are not static and describe scientists' changing roles. The differences appear in cores and bridging cores over time. These changes show research group dynamics and can naturally involve departmental turnover. Some structures were found to fit the small-world model, having only a few actors able to establish extra-departmental contacts.

There are some observed "transient" actors who move from cluster to cluster. Other "continuous" actors tend to pursue a line of research. They begin in a somewhat diffuse cluster characterised by publications in conference proceedings and later are found in other clusters (e.g., the actors 58 and 48), which shows that they can attract collaborators. They constitute a small group of highly productive scientists, as compared to the large pool of lower-ranking local researchers. As hubs, they play a specific bridging role within the network. According to Wagner and Leydesdorff (2005), when researchers seek a collaborator, they seek someone who is well connected and highly reputed and therefore has access to resources. The continuants meet these conditions. This also supports the findings reported by Braun et al. (2001) that continuants are mediators for other co-authors within a field. Finally, two "terminators" were identified: authors 62 and 68. They played a leading role in the early periods, creating groups of co-authors and interacting with junior team members to raise productivity and credibility within their field. Thus, newcomers and transients potentially gained greater visibility by working with researchers of renowned (Melin 2000) who, like "continuants", constitute hubs within their scientific networks by attracting collaborators.

The differences in actors' categories given in Table 1 illustrate the comings and goings of students, departmental and foreign researchers and researchers from the other disciplines. Miguel (2009) showed that contacts with other disciplines were primarily the result of DHUBI researchers' participation in extra-departmental group projects, mainly in the areas of humanities and social science, e.g., literature, linguistics, history and the publishing industry. Contrary, projects in more specific disciplines seldom involved partners

Table 1 Participation in DHUBI projects and papers by researcher category

Actors category	2001–2003		2004–2006		2007–2009	
	Actors	(%)	Actors	(%)	Actors	(%)
Researcher DHUBI	19	59.4	20	55.6	19	50.0
Student/graduate DHUBI	4	12.5	9	25.0	9	23.7
Argentine researcher LIS	1	3.1	1	2.8	0	0.0
Foreign researcher LIS	0	0.0	3	8.3	3	7.9
Argentine researcher other discipline	8	25.0	3	8.3	7	18.4
Foreign researcher other discipline	0	0.0	0	0.0	0	0.0
Total	32	100.0	36	100.0	38	100.0

from the other disciplines. An active strategy of seeking for extra-institutional partners, both domestic and foreign, should be implemented. The collaboration patterns also carry implications for staff training and mobility. Knowing author categories (e.g., student, professor, in the same or a different discipline, in the same or another institution) is instrumental both to determine researcher mobility and to hire outside staff or awarding international scholarships or visiting scholar grants. When weaknesses such as insufficient internationalisation and interdisciplinarity are identified, the institution/department has to apply policies to fill the gaps. Similarly, knowing how to encourage for meeting international standards (such as publishing more papers in English and in international journals) is extremely helpful when determining research incentives and promotion criteria.

Publication and collaboration patterns

An analysis of each author's specific role over time and his/her output reveals the relative weight of the types of publications (articles vs. papers published in conference proceedings) and the type of collaboration involved (national, international or even interdisciplinary).

While in the first period the actor 62 was, structurally speaking, a bridging author in *cluster 1*, his initial ability to attract partners waned in next periods. He collaborated with domestic colleagues only, published only in Spanish-language Argentinean journals and produced a high proportion of conference proceedings (with a ratio of 5:1). This publication pattern did not change over time as show the Table 2.

In 2001–2003, *cluster 2′s* four authors formed a structure resembling the "small world" model with the author 44 as the bridge to the authors from the other clusters. The most prominent feature of their output was the journal articles with high percentage (60 %) according to all publications. While most of the articles were published in domestic journals, they balanced their participation in national and international conferences. The proportion of single authorship and national co-authorship of journal articles was nearly equal, whereas domestic collaboration predominated in conference papers (87.5 %). The proportion of articles increased slightly in 2004–2006 (65 %), while most presentations were submitted to international conferences. Partnering continued to be primarily national. In the period 2007–2009, the major change was that more authors published conference papers than journal articles. In fact, the figures for the last period reversed: 35 % of the output consisted of articles and 65 % of conference publications, all of which were

Table 2 Productivity and internationalisation

2001–2003							2004–2006							2007–2009						
Cluster	Authors	Articles	Prod	% int_j	No. conf	% int_c	Cluster	Authors	Articles	Prod	% int_j	No. conf	% int_c	Cluster	Authors	Articles	Prod	% int_j	No. conf	% int_c
1	1	3	3.0		8	62.50	1	2	2	1.0	100.00	10	20.00	1	6	6	1.0	33.33	11	
2	4	14	3.5	7.14	10	40.00	2	6	3	0.5	33.33	26	15.38	2	2	2	1.0	100.00	5	20.00
3	6	8	1.3		8	87.50	3	3	0	0.0		3		3	2	2	1.0	100.00	4	25.00
4	4	6	1.5	16.67	2	50.00	4	1	2	2.0	50.00	2		4	4	2	0.5	100.00	2	
5	6				18	66.67	5	5	11	2.2	90.91	6	66.67	5	4	4	1.0	0.00	10	30.00
6	4				6	33.33	6	1	0	0.0		4		6	1	4	4.0	100.00	6	50.00
7	5	4	0.8		4	25.00	7	1	0	0.0		4		7	5	8	1.6	100.00	8	62.50
8	2	1	0.5		3		8	3	3	1.0	100.00	6	16.67	8	4	0	0.0		9	22.22
							9	4	2	0.5	100.00	2		9	1	0	0.0		10	0.00
							10	8	7	0.9	71.43	16	14.29	10	9	7	0.9	75.00	11	27.27
							11	2	1	0.5										

Authors, number of authors in each cluster; articles, number of articles published in journals; prod, ratio between number of articles and number of authors; int_j, percentage of papers published in international journals; conf, number of articles in conference proceedings; int_c, percentage of articles in international conference proceedings submitted to the domestic events. Despite the high proportion (80 %) of articles published in national journals, some papers began to be published in foreign journals.

In the first period, the group in *cluster* 3 adopted a "small world" structure, with all its members linked to the author 62 (from another cluster). Their output was distributed evenly between articles and proceedings (50 % each). There was no international collaboration and papers were published in domestic journals only. By contrast, all the conferences attended were international.

The publishing and collaboration patterns for the first three clusters were similar according to the considered indicators. Conference papers prevailed over journal articles, co-authors were primarily Argentinean and research results were published mostly in domestic journals.

During the first period, authorship in *cluster* 4 was characterised by a larger number of articles than conference papers, exclusively publication in national journals and equal proportions of papers published in national and international conference proceedings. From 2004 to 2006, only the author 58 published well and had the ability to connect with researchers from the other clusters. While conference papers prevailed over articles and more articles were published in national journals, a few also appeared in international journals and, for the first time, were internationally co-authored. In 2007–2009 the authors from this cluster got partners from the other groups. Although the author 58 continued to connect with the other clusters, his output was limited to the conference proceedings.

Cluster 5 published only conference papers. This group was practically isolated, with the exception of the actor 34, whose connections with another cluster, established in the initial period, were retained in the following 6 years.

Cluster 6 can be defined as semi-periphery. These actors were linked to actors from the other clusters this diverse cluster, which was not a formal research group, published papers in conference proceedings and international journal articles. The co-authorship ties were limited to the author 62. Only the authors 1, 22 and 48 continued to appear in the cluster in the next two periods. Finally, *cluster 7* was peripheral. This cluster revealed that actors' behaviour can be very uneven.

The publication patterns showed that while most authors published locally in Spanish language journals, with a low level of citation and collaboration, the impact was greater if articles were published in international journals (Table 3). The co-authorship rates were relatively low in all types of publications and in all clusters. These findings provide partial support for the working hypothesis. Productivity and visibility of the actors form the semi-periphery or periphery was very similar to the core ones. The actors from the semi-periphery and the periphery partnered sporadically with some of the core authors. They benefited from the production levels and visibility attained by actors with a long track for generating research partnerships. These results are consistent with the assumption adopted by Mali et al. (2010), according to which scientists, especially researchers in small scientific communities, are more successful when they work with researchers or research groups from other countries.

The high percentage of conference papers listed in Table 4 merits a comment, as conference participation and journal articles seek somewhat different aims. In addition to disseminating knowledge, physical encounters are a very important vehicle for relations among researchers, who tend to be what Price and Beaver (1966) referred to as "invisible colleagues". Papers presented at conferences are often published as proceedings but rarely become journal articles. The use of conference proceedings as means for disseminating research results is normal practice in the soft sciences, even though it is discouraged (Hurd 2000). As Laudel (2002) reports, about half of all scientific collaboration is invisible

Table 3 Visibility in journals

	Articles	Language			Coauthorship	Productivity mean	Articles with SJR	SJR mean 2001–2008	Q1	Q2	Q3	Q4
		es (%)	en (%)	pt (%)								
National journals (K)	18	100	–	–	2.16	0.46	2	0.03	0	0	0	2
International journals (K)	17	76	24	–	2.71	0.37	8	0.06	1	1	0	6
National journals (S_P)	15	100	–	–	1.80	0.56	2	0.05	0	0	0	2
International journals (S_P)	12	80	20	–	2.90	0.34	8	0.07	1	2	0	5

K = Core; S_P = Semi-periphery and periphery; es = Spanish; en = English; pt = Portuguese; coauthorship = number of author by article in each category; productivity mean = average of articles by author in each category; articles with SJR = number of articles with impact factor (SJR) in Scopus; sjr mean = average of SCImago journal rank; Q1, Q2, Q3, Q4 = quartile in the SCImago journal and country rank in which the journal is ranked

Table 4 Visibility in Conference Proceedings

	Congress	Language			Coauthorship	Productivity mean
		es (%)	en (%)	pt (%)		
National congress (K)	42	100	–	–	2.73	0.37
International congress (K)	18	94	6	–	2.55	0.39
National congress (S_P)	50	100	–	–	2.26	0.44
International congress (S_P)	19	63	30	7	2.80	0.36

because it does not result with a co-authored paper or formal acknowledgment in scientific publications. The publication patterns for such results are therefore more characteristic of the initial stages of a given discipline than of consolidated group efforts.

These patterns are common in some emerging fields in the social sciences and humanities, where international publications and collaboration are very recent. Nonetheless, some authors are able to establish international contacts and publish in international journals. And those are the articles with the highest impact in terms of citations received. As a result, the small numbers of authors with international contacts who publish in international journals are much more visible than the rather larger number of those whose careers take the opposite turn.

Conclusions

Given the complexity of the collaboration networks and research group dynamics, this study does not aim to address the social aspects of knowledge transfer that have some effect on overall knowledge generation. The focus here was limited on quantitative data. Consequently, this article's contribution is the analysis of the positions and the roles within the given scientific field, i.e., an analysis of how scientists, by conducting joint research, help to build the intrinsic scientific structure.

The contribution to the field of bibliometrics is its novel application of blockmodeling to extract valid information at the micro level by studying the collaboration network structures in a specific field. This gives a new way to perceive actors and their roles in a group. The main difference between this approach and the usual analysis is that here actors are included according to their direct involvement with one or several researchers, even though they do not actually take part of the formal group. Blockmodeling identifies actors who play a distinct role in the structure. The idea is that the same methodology can be applied and tested in different fields of knowledge and with larger populations. In fact, the data used in this study are only an example of how powerful the proposed analytical approach can be.

In this study, blockmodeling detected a core-periphery structure with small multiple cores. The scientists from a core co-authored with all or most of the colleagues in this core. The scientists from a semi-periphery were involved in some partnering but followed no systematic pattern of collaboration. The authors from a periphery did not collaborated at all. Core-periphery structures with bridging cores are of particular interest because the centre of such structures is much more firmly consolidated. The structure identified here fits the "preferential attachment" model.

Actors' roles change over time. This methodology identifies even more specific types of researchers: newcomers, transients, continuants, and terminators. We have shown (graphically) that some authors who were most active in the first period were not active later. In the first period, they appeared to be in intermediate stages of their research career, with high production rates; later they tend to be less productive, when their scientific careers were near to the end. The dynamic nature of research groups entails significant transitioning, and the knowledge produced and published has both a contemporary or short-term horizon (whose dimensions can be studied) and a long-term horizon for subsequent generations of researchers.

The present study may have also implications for scientific policy. Some authors have suggested (Moed 2008) that the research funding agencies should periodically review the assessment systems implemented in each scientific discipline. Actors' inclusion in the collaboration network depends on how attractive a partner might be, and on the individual interests of researchers seeking to enhance their resources and reputation. Consequently, collaboration is essentially pragmatic and characterised by a fair degree of self-organisation. For this reason, collaboration policies must be coordinated by domestic efforts to increase research capabilities. As Wagner and Leydesdorff (2005) suggest, links between government and research institutions should be strengthened, and individual researchers should be made "stakeholders" in decision-making regarding to collaboration investments. Agencies should therefore not only review standard indicators (number of publications and journal impact) but also examine new criteria, methods or indicators such as suggested in this study. The methodology proposed here defines individual research profiles more fully, not considering only publications and their impact, but also the ability to establish contacts, set up research teams and jointly publish the results. For these reasons, this approach may be useful for agencies when reviewing the methods to be applied in research group appraisal, promotion and funding.

As in previous studies (Lancho-Barrantes et al. 2012; Chinchilla-Rodríguez et al. 2012) the results of our research may also give some recommendations for better publication and collaboration practice in a given department or research institution by encouraging publishing in journals with higher visibility and greater impact in the international scientific community. That in turn entails attracting more international partners and incentivising international collaboration with institutions abroad.

There are several possibilities how to use the proposed approach. One might be to apply the proposed methodology in other fields and further explore the knowledge structures that arise around collaboration. Such knowledge can provide objective information, clarifying the patterns of fruitful communication, and thus facilitate decision-making based on scientific information. It can result into recommendations for the enhancement of researcher or research group prestige. Such a perspective may likewise be useful when reviewing research policy and publication incentives at the departmental and institutional level.

Acknowledgments The authors wish to thank Claudia González for compiling the data, Vladimir Batagelj for his technical support and suggestions, anonymous referees for comments that improved the present analysis and Margaret Clark for editing the English text. This research was partially funded by the Spanish National Research Council under the project entitled "*Generación de herramientas cienciométricas para el análisis de la colaboración científica*" (Proyecto Intramural CSIC 200810I210).

References

Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. *Science, 286*, 509–512.

Barabási, A. L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica A, 311*, 590–614.

Bartneck, C., & Hu, J. (2010). The fruits of collaboration in a multidisciplinary field. *Scientometrics, 85*, 41–52.

Batagelj, V., & Mrvar, A. (2003). Analysis and visualization of large networks. In M. Jünger & P. Mutzel (Eds.), *Graph drawing software* (pp. 77–103). Berlin: Springer.

Beaver, D. (2001). Reflections on scientific collaboration (and its study): past, present, and future. *Scientometrics, 52*, 365–377.

Beaver, D. (2004). Does collaborative research have greater epistemic authority? *Scientometrics, 60*(3), 399–408.

Borgatti, S. P., & Everett, M. G. (1999). Models of core/periphery structures. *Soc Netw, 21*, 375–395.

Borner, K., Dall'Asta, L., Ke, W., & Vespignani, A. (2005). Studying the emerging global brain: analyzing and visualizing the impact of co-authorship teams. *Complexity, 10*(4), 57–67.

Bozeman, B., & Lee, S. (2005). The impact of research collaboration on scientific productivity. *Soc Stud Sci, 35*(5), 673–702.

Braam, R., & van den Besselaar, P. (2010). Life cycles of research groups: the case of CWTS. *Res Eval, 19*(3), 173–184.

Braun, T., Glänzel, W., & Shubert, A. (2001). Publication and collaboration patterns of the authors of neuroscience journals. *Scientometrics, 51*, 499–510.

Caníbano, C., & Bozeman, B. (2009). Curriculum vitae method in science policy and research evaluation: the state-of-the-art. *Res Eval, 18*(2), 86–94.

Chinchilla-Rodríguez, Z., Benavent-Pérez, M., Miguel, S., Moya-Anegón, F. (2012). International collaboration in medical research in Latin America and the Caribbean (2003–2007). *J Am Soc Inform Sci* (in press).

Chinchilla-Rodríguez, Z., Vargas-Quesada, B., Hassan-Montero, Y., González-Molina, A., & Moya-Anegón, F. (2010). New approach to the visualization of international scientific collaboration. *Inform Visualization, 9*(4), 277–287.

Doreian, P., Batagelj, V., & Ferligoj, A. (2005). *Generalized blockmodeling*. Cambridge: Cambridge University Press.

Ferligoj, A., Doreian, P., & Batagelj, V. (2011). Positions and roles. In J. Scott & P. Carrington (Eds.), *Sage handbook of social network analysis* (pp. 434–446). Newbury Park: Sage Publications.

Ferligoj, A., & Kronegger, L. (2009). Clustering of attribute and/or relational data. *Metodoloski zvezki (Adv Methodol Stat), 6*(2), 135–153.

Hurd, J. M. (2000). The transformation of scientific communication: a model for 2020. *J Am Soc Inform Sci, 51*(14), 1279–1283.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Res Policy, 26*, 1–18.

Kronegger, L., Ferligoj, A., & Doreian, P. (2011). On the dynamics of national scientific systems. *Qual Quant, 45*(5), 989–1015.

Kronegger, L., Mali, F., Ferligoj, A., & Doreian, P. (2012). Collaboration structures in Slovenian scientific communities. *Scientometrics, 90*, 631–647.

Lancho-Barrantes, B. S., Guerrero-Bote, V. P., Chinchilla-Rodríguez, Z., & Moya-Anegón, F. (2012). Citation flows in the zones of influence of scientific collaborations. *J Am Soc Inform Sci Technol, 63*(3), 481–489.

Laudel, G. (2002). What do we measure by co-authorship? *Res Eval, 11*(1), 3–15.

Leydesdorff, L., & Vaughan, L. (2006). Co-occurrence matrices and their applications in information science: extending ACA to the web environment. *J Am Soc Inform Sci Technol, 57*(12), 1616–1628.

Mali, F., Kronegger, L., & Ferligoj, A. (2010). Co-authorship trends and collaboration patterns in the Slovenian sociological community. *Corvinus J Sociol Soc Policy, 1*(2), 29–50.

Melin, G. (2000). Pragmatism and self-organization: research collaboration at the individual level. *Res Policy, 29*(1), 31–40.

Miguel, S. (2009). Oportunidades y desafíos actuales de la investigación en Bibliotecología y Ciencia de la Información. El caso del Departamento de Bibliotecología de la Universidad Nacional de La Plata, Argentina. *Información, Cultura y Sociedad*, (21), 51–67. http://www.scielo.org.ar/pdf/ics/n21/n21a04.pdf.

Miguel, S., Chinchilla-Rodríguez, Z., González, C., Moya-Anegón, F. Analysis and visualization of the dynamics of research groups through a comparative input/output perspective. *Information Research* (in press).

Moed, H. F. (2008). UK research assessment exercises: informed judgments on research quality or quantity? *Scientometrics, 74*, 141–149.

Moody, J. (2004). The structure of a social science collaboration network: disciplinary cohesion from 1963 to 1999. *Am Sociol Rev, 69*(2), 213–238.

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *Proc Nat Acad Sci US, 98*(2), 404–409.

Newman, M. E. J. (2004). Coauthorship networks and patterns of scientific collaboration. *Proc Nat Acad Sci USA, 98* (Suppl. 2), 16, 404-409.

Newman, M. E. J. (2004b). Who is the best connected scientist? A study of scientific coauthorship networks. In E. Ben-Naim, H. Frauenfelder, & Z. Toroczkai (Eds.), *Complex networks* (pp. 337–370). Berlin: Springer.

Onofrio, M. G. (2009). The public CV database of Argentine researchers and the 'CV-minimum' Latin–American model of standardization of CV information for R&D evaluation and policy-making. *Res Eval, 18*(2), 95–103.

Perianes-Rodríguez, A., Chinchilla-Rodríguez, Z., Vargas-Quesada, B., Olmeda-Gómez, C., & Moya-Anegón, F. (2009). Synthetic hybrid indicators based on scientific collaboration to quantify and evaluate individual research results. *J Informetr, 3*(2), 91–101.

Persson, O., Glänzel, W., & Danell, R. (2004). Inflationary bibliometric values: the role of scientific collaboration and the need for relative indicators in evaluative studies. *Scientometrics, 60*(3), 421–432.

Price, D. (1963). *Little science, big science*. New York: Columbia University Press.

Price, D., & Beaver, D. (1966). Collaboration in an invisible college. *Am Psychol, 21*, 1011–1018.

Price, D. J. S., Gürsey, S. (1976). *Studies in scientometrics. Part 1. Transience and continuance in scientific authorship*. International Forum on Information and Documentation No. 1, pp. 17–24.

Shaw, D., & Vaughan, L. (2008). Publication and citation patterns among LIS faculty: profiling a "typical professor". *Libr Inform Sci Res, 30*(1), 47–55.

Sonnenwald, D. (2007). Scientific collaborations. *Annu Rev Inform Sci Technol, 41*, 643–681.

Wagner, C. S., & Leydesdorff, L. (2005). Network structure, self-organization, and the growth of international collaboration in science. *Res Policy, 34*, 1608–1618.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*, 440–442.

White, H. D. (2003). Author cocitation analysis and pearson's r. *J Am Soc Inform Sci Technol, 54*(13), 1250–1259.