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R&D collaboration in 50 major Spanish companies

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Abstract

Purpose: Although the role of enterprise in R&D is broadly acknowledged, few attempts have been made to gather data for analyzing the nature and scope of private sector collaboration.
Design/methodology/approach: The study aimed to deliver empirical results based on quantitative data to gain insight into the role of private enterprise as an indispensable actor in scientific development and innovation. To this end, an analysis was conducted of the contribution made by Spanish business, focusing on the 50 most active companies in terms of internationally visible scientific output, from three perspectives.
Findings: The findings provide insight into business involvement in the R&D system based on research papers published; national, international and sectoral collaboration patterns; structural patterns; and the identification of the most prominent firms from a systematic comparison of their research results and their position in the resulting collaboration network.
Research limitations/implications: Bibliometric analyses do not measure all types of publications. Indicators are usually based on data in the Thomson Reuters databases, which are regarded to be representative of peer-reviewed, publicly accessible papers with high international visibility and impact. The Thomson Reuters databases feature a series of advantages that make them indispensable for studies on scientific collaboration.
Originality/value: One of the core ideas of this study is the emphasis on the essential role of collaboration in improving scientific results, as borne out by the correlation between the clustering coefficient and the hybrid indicators. The findings also provide proof of the success of strategies for institutional collaboration. The foregoing shows that the application of hybrid indicators to institutional aggregates yields novel results not explored in preceding studies.
Keywords: R&D cooperation, enterprise, scientific collaboration, network analysis, Spain
Paper type: Research paper

1. Introduction

Science and technology play an indisputable role in a country's development. The increase in R&D investment in countries such as Spain when crisis strikes, as it has now, is essential to ongoing social and economic progress.

Knowledge transfer and fluent relations among the actors involved in scientific and technological development are the keys to improving system performance. In this regard, an increasing number of studies have analyzed the relationships between the universities and research centres that generate knowledge on the one hand, and private enterprise that transforms knowledge into goods usable by society on the other.

A variety of indicators help measure such collaboration: co-authorship of scientific papers, joint participation in patents, shared research agreements, hiring of university graduates by private enterprise and practising professionals' participation in formal education, to name a few. Nonetheless, the availability of such information is limited or even non-existent in some respects, and where it does exist, the aggregates tend to be scantly comparable (Tijssen RJW et al., 2009).

Prior research relating to the present study has focused on the analysis of enterprise involvement in the Research and Development (R&D) system. Many papers have analyzed the relationships among universities, industry and government agencies, the so-called triple helix metaphor (Etzkowitz H and Leydesdorff L, 1997). Some focus on the study of the structures, cultures, routines and characteristics of the various types of institutions based on scientific publications, a method widely used in international comparisons, in which the contribution to an understanding of economic development is defined to be a product (Calvert J and Patel P, 2003), (Howard J, 2005), (Leydesdorff L, 2003), (Leydesdorff L and Meyer M, 2006). Others address the implications of the metaphor in the context of regional policy (Danell R and Persson O, 2003), (Jaffe AB, 1989), (Jaffe AB, 1993) and technological progress published in reputed journals (Narin F et al., 1997). Yet others assume that knowledge and learning lie at the core of innovative systems and are the new lead players in the economy and society (Etzkowitz H and Leydesdorff L, 2000), (Lundvall BA, 1995). Some authors concentrate on the motivation underlying collaboration (Mora Valentín EM, 2002), the use of scientometric indicators to analyze collaboration (Leydesdorff L et al., 2006) or the importance of collaboration as a paradigm for moving from to linear to interactive models for innovation (Muñoz E, 2001). Bibliometric indicators are likewise used to analyze regional differences in scientific and technological development (Gómez I et al., 2005). Even the effect of public R&D policies on national (Schilling P, 2005) or regional (Braczyk HJ et al., 2003), (Cooke P et al., 1997), (Cooke P and Memedovic O, 2003), (Sanz Menéndez L et al., 2001) scientific and technological output has been analyzed.

All these studies analyze the measures adopted or that should be adopted to improve the transfer of scientific and technological findings from public institutions to industry. Most of these papers focus on the triple relationship (university-industry-government), either with a detailed description of the relevant role of universities or the effect of public policies on science funding. Despite the growing interest, however, few attempts have been made to gather data with which to analyze the nature and scope of collaboration with a focus on private enterprise.

This article makes a quadruple contribution to the analysis of the role of R&D collaboration by businesses based on the co-authorship of scientific papers. First, it analyzes private enterprise participation in research by specialities. Second, it examines the geographic distribution of national and international collaboration. Third, it studies the mechanisms for collaboration with other sectors involved in research. Fourth, it undertakes a structural analysis of the relationships generated by the companies analyzed. This endeavour involved an in-depth analysis of the data on the 50 predominant Spanish companies in terms of scientific output.

The paper is organized as follows: section 2 describes the issues addressed in this study. Section 3 reviews the methodology used. Section 4 reports the findings. Section 5 discusses the results and their scope. Section 6 summarizes the highlights of the study and their possible implications for both private enterprise and research policies.

2. Research questions

This paper aims to answer a number of questions about companies' involvement in the development of Spanish research: What is their present role in the scientific scenario? Where are the major producers located? Which scientific specialities are the most productive? Who are their main partners? What is their position on the resulting co-authorship networks? Fortunately, all the issues and characteristics explored in this study can be addressed with the information available in publicly accessible scientific publications, as explained below.

The study aimed to deliver empirical results based on quantitative data to gain insight into the role of private enterprise as an indispensable actor in scientific development and innovation. To this end, an analysis was conducted of the contribution made by Spanish business, focusing on the 50 most active companies in terms of internationally visible scientific output, from three perspectives. The first explored their involvement in the R&D system, measured in number of scientific papers published, and their distribution by subject area. The second consisted in a detailed review of their national, international and sectoral collaboration patterns. The third analyzed the resulting collaboration networks, their structural patterns and the identification of company prominence on the grounds of a systematic comparison of their research results and structural position.

3. Methods

The data source used was the Web of Science (WoS, 2008), a Thomson Reuters product that includes the following databases: 1) Science Citation Index Expanded (SCI- Expanded), specializing in science and medicine, 2) Social Science Citation Index (SSCI), specializing in social science and, 3) Arts and Humanities Citation Index (AHCI). Access to the WoS was cost-free thanks to the public service provided by Spain’s Ministry of Science and Innovation for Spanish researchers, through the Fundación Española para la Ciencia y la Tecnología (FECYT, Spanish foundation for science and technology).

As noted, bibliometric analyses do not measure all types of publications. Indicators are usually based on data in the Thomson Reuters databases, which are regarded to be representative of peer-reviewed, publicly accessible papers with high international visibility and impact. The Thomson Reuters databases feature a series of advantages that make them indispensable for bibliometric studies, particularly for studies on scientific collaboration. The choice of this particular source to obtain relevant bibliographic data from which to calculate the indicators used in this study was based on a number of considerations.

The first has to do with multi-disciplinarity and the match between the subject matters in these bases and commercial products. The idea was to obtain information on scientific disciplines and a number of geographic domains. This called for wide and uniform disciplinary coverage to ensure that the comparisons would be as evenly balanced as possible. In this regard, the WoS databases, with multi-disciplinary sources and broad coverage, are ideal for this purpose.

Nonetheless, in certain scientific domains and countries, journal publication is not the sole vehicle for disseminating production. In social science and humanities, for instance, monographs are the instrument most prevalently used. Similarly, in engineering and technological disciplines, technical reports, an important and frequently the preferred medium, are not always converted into scientific papers. As a result, the impact of monographs differs widely from the impact obtained by scientific papers (Hicks D, 2004). Furthermore, in the case of social science and humanities production in Spain, the preferred channel tends to be national journals rather than international journals with established impact factors (Gómez I et al., 2004). Added to the predominance of a local focus in such literature, such limitations preclude the exclusive use of the above databases for assessing and comparing domestic output in these subject areas to production in experimental and biomedical science, for instance, which is better represented in WoS bases (Archambault E and Gagné EV, 2004), (Moed HF, 2005).

Although over the years the these bases have been criticized for what has been regarded to be limited coverage of disciplines, languages and countries (Andersen H, 2000), more recent studies have concluded that with the exception of Germany in agriculture and France as a science publisher, journal coverage in the SCI and the Journal of Citation Reports (JCR) is well balanced with respect to the journals listed in Ulrich's Science & Technology, the most complete database of journal titles, with over 220 000 listed in 1998 (Braun T et al., 2000). As a general rule, the chief scientific periodical publishers are over-represented both in the SCI and the JCR, along with English language social science and humanities journals, but neither of these drawbacks affects the objectives of the present study.

A second advantage to this type of tools is their structure, which distinguishes them from other similar databases. Their added value lies in the importance attached to the information on the institutional affiliation of all the authors of a given paper. This information can be used for detailed analyses of scientific collaboration.

A third reason justifying the choice of these sources is that they contain all the bibliographic references given in the papers listed. With this information, a basis can be established for calculating essential bibliometric indicators, relating, for instance, to collaboration and the impact of scientific literature.

Moreover, supplementary information on journals was retrieved from the JCR (JCR, 2007). This database includes information on journals in the WoS and their visibility indicators, such as the well known impact factor.

Lastly, the information used to classify companies by size and specific business profile was drawn from the *Sistema Anual de Balances Ibéricos* (SABI, yearly Iberian balance sheet system), which contains financial information on Spanish and Portuguese companies since 1990.

3.1. Data

Records for the period 1995-2005, inclusive, were retrieved from the above databases. The initial search criterion was all papers in which Spain appeared in the address field. The initial search results yielded a total of 298 962 papers of all kinds published by Spanish authors. The address field was subsequently standardized to reliably determine the institution, sector and region for each bibliographic record. The sub-set of papers attributable to private enterprise contained a total of 7 702 elements.

These data were used to create a relational database. The information contained in the JCR on each journal was added, namely: bibliographic identification, number of papers published by year, subject category and impact index by year.

3.2. Data Standardization

Several fields in the database had to be standardized, in particular both authors' and institutional names, to suitably analyze and mine the data. The address field usually comprises four levels: main organization, department within the organization, city and country. In many cases, only three levels are listed, excluding the department or institutional level. The country is generally highly standardized and the city can be standardized using postal codes. Many variations can be found at all these levels, however. This is one of the problems that had to be solved, for it could have directly affected the relationships generated among the institutions producing scientific information. The procedure followed involved locating the variations in each institution's name, choosing an acceptable denomination that encompassed them all, and attributing it to the respective region semi-automatically.

3.3. Indicators

Three types of indicators were used:

Bibliometric indicators: P is the total number of papers. P col is the total number of co-authored papers. Citations is the total number of times all the papers were cited. Cites per document relative to the scientific field (RCD): this indicator shows the average scientific impact of an institution's publication output in terms of citations per documents. Shown values express average citations received by the institution's published documents over the whole period. The values are affected by institution research profiles. The normalized impact factor (NIF): the expected impact is obtained for each periodical appearing in the JCR from the Impact Factor (IF). The expected impact factor used here as an indicator is calculated on the basis of the following premises: each scientific paper automatically inherits the IF, defined in the JCR, of the journal where it is published. Each paper is assigned the IF corresponding to the year of publication and, wanting that, the factor for the closest year available. This is subsequently normalized with a procedure that accommodates comparative terms. A normalization procedure based on typification (Braun T et al., 1985), generates IF values that conserve their variability while harmonizing the scales of the various subject categories. This yields the optimal reference point on which the domain analyzed should be positioned, whereas in other types of calculations the resulting value is given as a range.

The NIF is found with the following formula:

$$nif_{jc} = \frac{if_{jc} - \overline{if}_c}{\delta if_c} -$$

Where *if* is the impact factor for journal j in JCR category c and *nif* is the normalized impact factor of journal j in JCR category c (Olmeda Gómez C et al., 2009). A value larger than 1 means that, on average, the papers of an institution have been published on journals whose importance is above the average in its scientific field. Whereas a value smaller than 1 means that, on average, the papers of an institution have been published on journals whose importance is below the average in its scientific field. Research power (RP) weights the expected visibility by the number of papers authored by the institution analyzed, and is defined as the summation of the product of output times the

NIF. The internationalization index gives the percentage of papers written in collaboration with non-Spanish partners with respect to the total published (Chinchilla-Rodríguez Z, 2006).

Structural indicators: degree, in turn, is the simplest and most intuitive way to measure graph centrality, and is defined to be the number of actors to whom an actor is directly linked. This measure of centrality ranks actors by their number of direct relations in the network as a whole (Degenne A and Forsé M, 1999), (Hanneman RA and Riddle M, 2005), (Herrero R, 2000), (Mrvar A, 2000), (Rogers EM and Kincaid DL, 1981).

$$C_D\left(n_i = \frac{d(n_i)}{N-1}\right)$$

Where *d(ni)* is the actor's degree and *N* the total number of nodes in the network. Betweenness is the frequency with which a node appears on a geodesic connecting two other nodes (Mrvar A, 2000):

$$C_B(v) = \sum \frac{\delta_{st}(v)}{\delta_{st}}$$

Where *σst* is the number of shortest paths from *s* to *t*, and *σst(v)* is the number of shortest paths from *s* to *t* that pass through a vertex *v*. The clustering coefficient (CC): a clustering measure must be defined if evidence usable for evaluating authors' scientific collaboration is to be obtained. Watts and Strogatz introduced what they called the clustering coefficient. The following example explains the idea simply: if A cooperates with four authors and they in turn have all worked together, each of them can be connected by a tie, generating a total of six such links. Now assume that one of A's partners does not collaborate with the others. The number of ties in this case will be less than six. Here the clustering coefficient of A's circle of partners is obtained by dividing the actual by the total possible number of ties (Watts DJ and Strogatz SH, 1998).

The CC, then, indicates the density of the relationships among the partners around a given node. Values close to one denote a high rate of collaboration among the actors. Figures close to zero, by contrast, mean that the node is the sole tie among partners (Barabási AL, 2002).

This indicator has been used, for instance, in studies analyzing research projects awarded by the European Union, albeit as a global structural indicator to estimate the degree of network cohesion rather than to evaluate individual actors (Wagner CS and Leydesdorff L, 2005).

The CC is defined as follows (Batagelj V and Mrvar A, 2004):

$$CC(v) = \frac{|E(G_1(v))|}{|E(G_2(v))|} \qquad CC'(v) = \frac{\deg(v)}{MaxDeg} CC(v)$$

Where *deg(v)* is the degree of vertex *v*, *|E(G1(v))|* is the number of ties among the vertices in neighbourhood 1 around vertex *v*, *MaxDeg* is the maximum degree attained by any vertex in the network and *|E(G2(v))|* is the number of ties or edges among the vertices in neighbourhoods 1 and 2 around vertex *v*. If *deg(v)* is less than or equal to one, all the coefficients for this vertex will be zero. Hybrid indicators: the popularity Index provides a measure that weights the number of papers (popularity) by the cohesion of each node's collaboration pattern. The prestige index adjusts the number of citations (prestige) for the degree of cohesion of each author's collaboration pattern. But such prominence or popularity should be scaled or supplemented by indicators that reflect and distinguish among popular nodes. In this regard, Mählck and Persson noted that information visualization analysis would benefit if an appropriate combination of bibliometric and structural magnitudes could be found, able to characterize and put into perspective the observations about the actors drawn from the graphs obtained, which would always be supplementary to existing indicators (Mählck P and Persson O, 2000).

To this end, we use a combination of known structural and bibliometric indicators: node clustering coefficient, output and number of citations referring to such output.

$CC^{'}(v) \times P(v)$	$CC^{'}(v) \times ncitations(v)$
Popularity Index	Prestige Index

Where *P(v)* is total node *v* output in the period and *ncitations(v)* is the total number of citations observed for the same node and period.

The clustering coefficient is what relates the bibliometric popularity (number of papers) and prestige (number of citations) indicators to the author's collaboration practices. A new measure can therefore be obtained with which to distinguish between two authors with the same productivity or number of citations. Authors with more cohesive networks of collaborators are regarded to be more "popular" or "prestigious".

The choice of this indicator affords certain advantages over the typical centrality measures (degree, betweenness and closeness), which determine an actor's prominence with respect to other members of the network, but only in terms of relations with the node analyzed. The clustering coefficient, by contrast, evaluates not only the number of relationships (co-authored papers), but also the degree of inter-relationship among neighbouring nodes. Therefore, an actor's prominence is not defined solely by the number of inter-connected authors, but by his/her participation in a "neighbourhood" where collaboration is open to everyone, and not only to the actor in question.

In short, the popularity index provides a measure that weights the number of papers (popularity) by the cohesion of each node's collaboration pattern. Analogously, the prestige index would qualify the number of citations (prestige) by the degree of cohesion of each author's collaboration pattern. Such hybrid indicators embody a new approach to research, placing the necessary weight on the degree of collaboration among researchers, which has been ignored to date, despite its vital importance for science and technology policy managers (Perianes-Rodríguez A et al., 2009), (Perianes-Rodríguez A et al., 2010).

4. Results

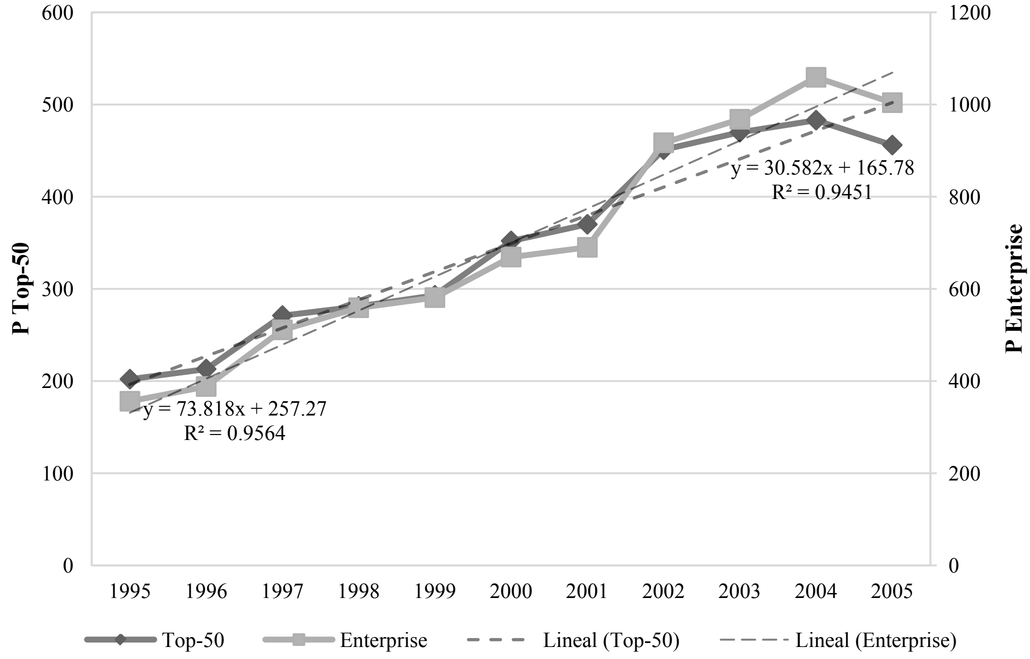
4.1. Specialities

In absolute numbers, a total of 1 381 Spanish companies engaged in national scientific production in the period studied, which together produced only 2,58 % of the country's total output with international visibility.

As noted, this study reviews a number of aspects of scientific collaboration as practised by the 50 most productive companies conducting business in Spain.

The first such aspect refers to the specialization of their research. Figure 1 graphs scientific output by these companies and private enterprise in general between 1995 and 2005. The curves for both were characterized by a steady and nearly parallel rise.

Figure 1. Scientific output by Spanish private enterprise as a whole and the top 50 firms, 1995-2005



The similarity in the two patterns is surely related to the fact that the top 50 companies (3,62 % of the total number) account for nearly 50 % of the co-authored papers produced by the private sector (3 842 papers).

Table 1 gives the absolute data on top 50 company production by speciality. Speciality definitions were based on the JCR subject categories into which the publishing journals are classed. These categories were subsequently grouped into the 26 major divisions of scientific knowledge defined by Spain's National Assessment and Prospective Studies Agency (ANEP, 2009). ANEP's expert evaluators assign to each ANEP class the ISI-JCR categories they deem appropriate. As in the ISI-JCR, one and the same category can be listed under different ANEP classes. The use of journal classifications to divide and then reclassify articles into subject categories, is widely accepted in bibliometric studies (CINDOC, 2006), (Glänzel W and De Lange C, 2002), (Katz JS et al., 1995), (Ma N and Guan J, 2005) and has been proposed and used as a unit for visualizing specific scientific domains (Moya-Anegón F et al., 2004). The ANEP divisions are quite similar to the 27 subject areas defined by Scopus (Scopus, 2004).

Table 1. Scientific output by the top 50 Spanish firms, 1995-2005

Organization	P	Main class	% Main class	Specialty
Prous Science	323	323	100	Physiology and pharmacology
Glaxo SmithKline	312	178	57.05	Molecular biology
PharmaMar	288	176	61.11	Medicine
Lilly	279	143	51.25	Medicine
Almirall	254	143	56.30	Medicine
Merck Sharp Dohme	160	57	35.63	Medicine
REPSOL	155	88	56.77	Materials science
Pfizer	147	134	91.16	Medicine

ALK Abello	113	108	95.58	Medicine
Leti Laboratories	103	96	93.20	Molecular biology
Uriach	95	41	43.16	Physiology and pharmacology
Ferrer Group	93	55	59.14	Physiology and pharmacology
Esteve	91	52	57.14	Physiology and pharmacology
Menarini	72	40	55.56	Physiology and pharmacology
Bayer	58	52	89.66	Medicine
Telefonica	54	23	42.59	Electronic technology
Mar&Gen	53	51	96.23	Medicine
Novartis	53	45	84.91	Medicine
Aventis	52	50	96.15	Medicine
Ingenasa	49	42	85.71	Molecular biology
Carburos Metalicos	44	33	75	Chemistry
Merck Farma	42	28	66.67	Medicine
Abbott Laboratories	41	31	75.61	Medicine
FAES Farma	41	24	58.54	Physiology and pharmacology
Tamag Iberica	41	38	92.68	Physics
PULEVA	40	25	62.50	Food science and technology
INESCOP	40	30	75	Materials science
Cantabria Pharmac Industries	39	25	64.10	Medicine
Biomar Institute	39	26	66.67	Physiology and pharmacology
Bristol Myers Squibb	39	35	89.74	Medicine
ARCELOR	39	24	61.54	Chemical engineering
ANFACO	39	27	69.23	Molecular biology
Knoll	37	21	56.76	Medicine
Abbott Nutrition	36	27	75	Medicine
Labein	36	13	36.11	Computer science
AstraZeneca	35	34	97.14	Medicine
Alcatel	35	34	97.14	Electrical engineering
Schering Plough	34	28	82.35	Medicine
Antibioticos	33	31	93.94	Molecular biology
Pharma Res	32	31	96.88	Medicine
Parke Davis	31	26	83.87	Medicine
Iberdrola	31	12	38.71	Physics
Sueno Lab	31	23	74.19	Medicine
Biometric Technologies	30	25	83.33	Medicine
Echevarne Laboratories	30	24	80	Medicine
Vita Laboratories	30	15	50	Medicine
INSA	29	24	82.76	Physics
Ifidesa Aristegui	29	25	86.21	Medicine
Janssen Cilag	27	24	88.89	Medicine
ACERINOX	27	12	44.44	Chemical engineering

In the table, *main class* is defined to be the most productive area, listed in the final column.

The data on top 50 specialization are aggregated in Table 2. Sixty eight per cent of the output dealt with some aspect of biomedicine. Other natural and experimental sciences together accounted for 22 %. By contrast, only slightly over 9 % of the papers dealt with technology and engineering.

Table 2. Top 50 company output by speciality

Speciality	% Institutions	% P
Medicine	11.11	30.32

Physiology and pharmacology	10.59	20.31
Molecular biology	10.08	15.22
Chemistry	8.53	9.48
Materials science	3.88	3.30
Food science and technology	6.46	3.08
Physics	4.91	2.72
Livestock and fisheries	5.68	2.62
Plant and animal biology	5.68	2.35
Agriculture	5.68	2.26
Electronics engineering	2.33	1.55
Electrical engineering	2.58	1.52
Chemical engineering	1.55	1.43
Computer science	4.13	1.02
Earth science	3.36	0.82
Psychology	4.13	0.72
Civil engineering and architecture	3.36	0.58
Mathematics	1.81	0.24
Social science	1.81	0.19
Aerospace. marine and mechanical engineering	1.29	0.17
Philosophy	0.52	0.07
Economics	0.52	0.03

4.2. National collaboration. Geographic distribution

The geographic distribution of the institutions participating in joint scientific production was also analyzed. The percentage of papers involving at least two national institutions came to 63,25 % of the total. Table 3 gives the geographic distribution of national collaboration among the top 50 firms. According to these data, institutions headquartered in the Community of Madrid participated in six of every ten papers. The second most active region was Catalonia, with 42 %. Nonetheless, joint research was conducted by more institutions headquartered in Catalonia (26,2 %) than in Madrid (25,9 %).

Table 3. Geographic distribution of top 50 company collaboration

Region	% Ndoc	% Institutions
Madrid	61.01	25.87
Catalonia	42.32	26.16
Andalusia	10.96	9.39
Valencia	7.65	8.82
Basque Country	7.00	4.77
Castile and Leon	4.79	4.34
Galicia	3.72	3.03
Asturias	3.18	2.75
Aragon	2.19	2.60
Castile-La Mancha	1.69	3.18
Navarre	1.67	1.59
Canary Islands	1.43	1.45
Cantabria	1.30	1.16
Murcia	1.22	2.02
Balearic Isles	0.75	1.01
Extremadura	0.65	1.16
La Rioja	0.29	0.72

These data are supplemented by the information in Table 4, which gives the geographic distribution of the top 50 institutions only and their scientific output. The table shows that companies working out of Madrid accounted for a little over half of the top 50 output, followed by Catalonian firms with 33 %, while 44 % of such companies have their main office in Madrid (44 %) and 30 % in Catalonia.

Table 4. Geographic distribution of top 50 companies

Aut. Comm.	% Ndoc	% Institutions
Madrid	54.26	44
Catalonia	33.10	30
Andalusia	4.97	10
Basque Country	2.75	6
Castile and Leon	1.86	4
Valencia	1.04	2
Asturias	1.01	2
Galicia	1.01	2

4.3. International collaboration

A third aspect analyzed was international collaboration among top 50 firms. Indeed, nearly one third (28,2 %) of the papers were co-authored with non-Spanish institutions. Table 5 shows the top ten partner countries by percentage of total joint studies and total international joint studies.

Table 5. International collaboration Top ten countries

Country	% P	Internationalization index
USA	11.84	42.01
England	4.50	15.97
Italy	4.14	14.68
France	4.06	14.40
Netherlands	3.02	10.71
Germany	2.19	7.76
Belgium	0.96	3.42
Switzerland	0.73	2.59
Sweden	0.65	2.31
Denmark	0.62	2.22

Table 6 groups output by continents. Nearly 90 % of the international joint papers involved a European institution. Around one half of the international papers was co-authored by institutions in the United States.

Table 6. International collaboration by continent

Continent	Internationalization index
Europe	89.20
America	50.51
Asia	2.12
Oceania	1.66
Africa	0.46

4.4. Sectoral collaboration

Another aspect studied was collaboration between the chief companies and other domestic sectors. In all, the top 50 network of institutional collaboration comprised 692 organizations. Table 7 shows the percentage of institutions by sector and the percentage output for each.

Table 7. Top 50 company collaboration by domestic sector

Sector	% Institutions	% P
Health System	59.39	29.93
Private enterprise*	9.83	3.98
University	7.51	34.67
National Res. Counc.	4.77	6.59
Government	4.19	1.46
Other sectors	3.47	1.56
Univ-CSIC Centres	2.75	2.06
Public institutes	0.87	0.68

* Excluding the top 50

Nearly 60 % of the institutions with which the top 50 firms partnered formed part of the health system, although the respective output accounted for just 30 % of all co-authored papers. By contrast, while only 7,5 % of the participating institutions were universities, they co-authored 35 % of all joint studies. Conversely, the 10 % of private company partners (outside the top 50) produced barely 4 % of the total joint papers.

4.5. Network analysis

The last aspect analyzed was the position and prominence of top 50 companies in the institutional co-authorship network resulting from the preceding findings. Network analysis was used to obtain the structural indicators that supplement the bibliometric indicators. A suitable combination of the two types of indicators would provide a rough estimate of the prominence or importance of the organizations in the network.

Table 8 gives the main bibliometric, structural and hybrid indicators for the top 50 firms. As explained in the section on methodology, the first include number of papers, number of joint studies, number of citations, the normalized impact factor and the research power obtained for each institution. The second comprise degree, betweenness and the clustering coefficient. Finally, the popularity and prestige indexes are the result of combining bibliometric and structural indicators.

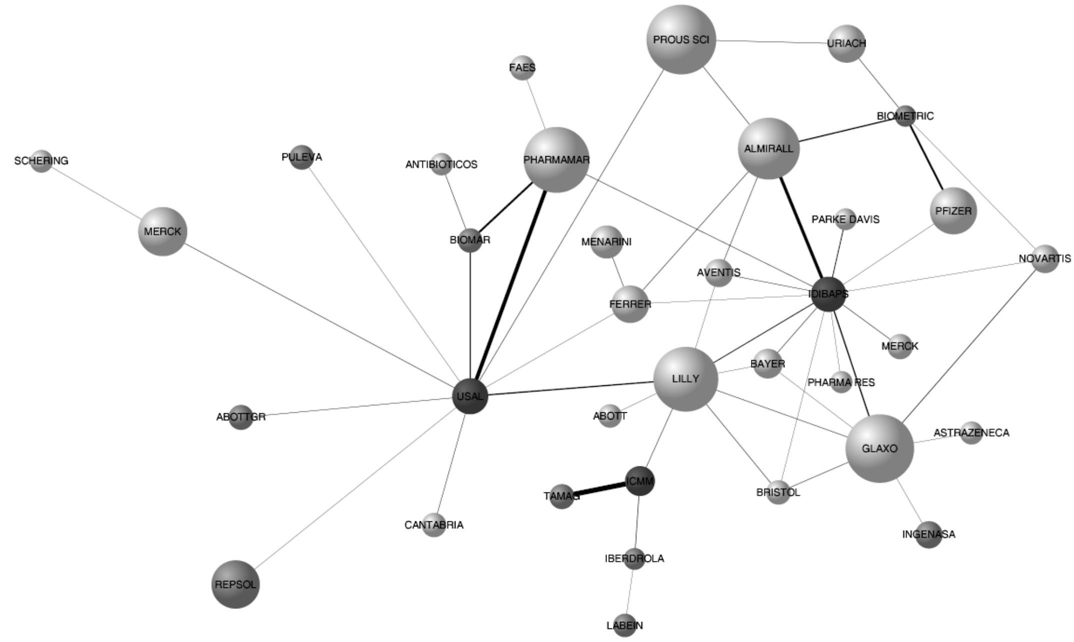
Table 8. Bibliometric, structural and hybrid indicators. Top 50

Organization	P	P col	RCD	NIF	RP	Degree	Betweenness	CC	Popularity	Prestige
Prous Science	323	22	0.002	0.8	9.28	0.013	0.0005	0.0001	0.038	0.0011
Glaxo SmithKline	312	229	0.111	1.2	204.6	0.2	0.0451	0.2031	63.353	81.2215
PharmaMar	288	101	0.029	1.1	71.75	0.059	0.0126	0.0049	1.404	0.7555
Lilly	279	165	0.065	1.1	105.8	0.224	0.07	0.2071	57.792	43.7063
Almirall	254	136	0.072	1.1	100.9	0.177	0.0283	0.1759	44.672	37.1097
Merck Sharp Dohme	160	65	0.043	1	44.76	0.198	0.0728	0.1873	29.964	14.7948
REPSOL	155	115	0.083	1.1	104.2	0.049	0.0215	0.0016	0.244	0.2979
Pfizer	147	139	0.035	1	43.64	0.165	0.0446	0.111	16.313	6.6586
ALK Abello	113	85	0.118	1.2	69.63	0.101	0.0233	0.0318	3.592	4.8954

Leti Laboratories	103	57	0.058	1.2	27.21	0.052	0.0093	0.0055	0.567	0.3800
Uriach	95	47	0.059	1	38.19	0.045	0.0052	0.0044	0.414	0.2832
Ferrer Group	93	54	0.060	1	44.71	0.071	0.0108	0.0109	1.018	0.7004
Esteve	91	35	0.021	1.1	27.22	0.077	0.0145	0.0193	1.759	0.4253
Menarini	72	44	0.065	1.1	33.66	0.071	0.0097	0.0155	1.118	0.8386
Bayer	58	49	0.175	1.1	35.97	0.171	0.0243	0.2398	13.909	28.0576
Telefonica	54	22	0.008	0.9	15.39	0.023	0.0086	0.0002	0.013	0.0007
Novartis	53	35	0.134	1.2	21.85	0.113	0.0214	0.055	2.916	4.5122
Mar&Gen	53	25	0.068	1.6	34.35	0.006	0.0001	0	0.001	0.0009
Aventis	52	50	0.052	1.1	32.17	0.093	0.0087	0.0377	1.962	1.1696
Ingenasa	49	19	0.040	1.2	20.85	0.019	0.0133	0.0002	0.009	0.0068
Carburos Metalicos	44	44	0.154	1.3	52.63	0.012	0.0012	0.0001	0.005	0.0116
Merck Farma	42	33	0.087	1.2	25.04	0.032	0.0028	0.0015	0.064	0.0638
Tamag Iberica	41	41	0.149	1	41.77	0.01	0	0.0002	0.009	0.0123
Abbott Laboratories	41	36	0.120	1.1	38.4	0.012	0.0002	0.0001	0.002	0.0032
FAES Farma	41	20	0.055	0.9	15.71	0.026	0.0033	0.0005	0.022	0.0141
INESCOP	40	36	0.115	1	34.56	0.009	0.0002	0.0003	0.012	0.0132
PULEVA	40	27	0.030	1	18.7	0.02	0.0038	0.0003	0.011	0.0062
ARCELOR	39	36	0.016	1.1	29.32	0.017	0.0025	0.0002	0.007	0.0016
Bristol Myers Squibb	39	34	0.147	1.1	18.1	0.09	0.0034	0.0375	1.464	2.4768
ANFACO	39	34	0.148	1.2	36.35	0.007	0.0001	0	0.002	0.0028
Cantabria Pharmac Indust	39	33	0.071	1	15.43	0.035	0.0039	0.0018	0.069	0.0570
Biomar Institute	39	29	0.057	1	25.02	0.027	0.0017	0.001	0.040	0.0420
Knoll	37	26	0.044	0.9	19.17	0.094	0.0318	0.0252	0.933	0.4792
Abbott Nutrition	36	34	0.094	1.1	20.38	0.081	0.0065	0.0267	0.963	0.9091
Labein	36	18	0.013	1.1	13.63	0.025	0.0091	0.0005	0.017	0.0014
AstraZeneca	35	34	0.007	0.9	7.41	0.082	0.0053	0.024	0.841	0.0721
Alcatel	35	11	0.022	1	9.14	0.009	0.0029	0	0.002	0.0002
Schering Plough	34	30	0.036	1.1	11.83	0.075	0.0055	0.0229	0.779	0.3207
Antibioticos	33	17	0.220	1.1	18.33	0.017	0.0012	0.0014	0.047	0.1207
Pharma Res	32	30	0.141	0.9	11.8	0.039	0.0017	0.0031	0.100	0.1626
Parke Davis	31	30	0.316	1.1	22.21	0.043	0.0018	0.004	0.124	0.4519
Iberdrola	31	22	0.073	1.1	22.72	0.027	0.0066	0.0008	0.023	0.0113
Sueno Lab	31	15	0.080	1.1	10.89	0.004	0	0	0.001	0.0005
Biometric Technologies	30	30	0.025	1	9.02	0.072	0.0042	0.0143	0.430	0.0717
Echevarne Laboratories	30	29	0.166	1.3	30.07	0.03	0.0042	0.0012	0.037	0.0611
Vita Laboratories	30	28	0.237	1	16.71	0.033	0.0035	0.0024	0.073	0.2003
INSA	29	25	0.292	1.1	25.52	0.017	0.0075	0.0003	0.009	0.0183
Ifidesa Aristegui	29	20	0.137	1.2	16.56	0.051	0.009	0.0045	0.130	0.2068
Janssen Cilag	27	26	0.096	1	18.18	0.054	0.0086	0.0064	0.174	0.1929
ACERINOX	27	23	0.143	1.1	23.5	0.014	0.0034	0.0002	0.004	0.0055

The graph in Figure 2, in turn, shows the structure of the network of top 50 firms only. This type of node-and-link schemes are used to highlight certain aspects of a network. In this case, the deliberate aim was to retrieve the relationships among the top 50 firms. Such invasive action has obvious consequences. As the figure shows, only 32 of the 50 companies initially forming the network appear in the graph, for the other 18 were eliminated for want of connections. Another prominent feature is the presence of three institutions outside the top 50, whose intermediation between companies guarantees network stability.

Figure 2. Schematic map of the network of top 50 firms



For graphic reasons, the node profiles were limited to three basic colours. The darkest identifies non-top 50 intermediaries. The lightest are pharmaceutical companies. The in-between shade represents all other engineering-materials-chemistry and biotechnology firms. The thickness of the lines representing the links is an indication of the number of joint studies conducted by the nodes in question.

5. Discussion

While accounting for only 4 % of the total, the sample of companies selected for this study produce nearly 50 % of the studies co-authored by companies, a clear indication of their relevance (figure 1).

Medicine, physiology and pharmacology are the three most productive areas of specialization.

Table 9. Top 50 company profile and size

Profile	Firms	% Firms
Pharmacology	29	58
Biotechnology	4	8
Chemistry	3	6
Engineering	3	6
Materials science	3	6
Medicine	3	6
Communications	2	4
Nutrition	2	4
Energy	1	2

Size*	% Firms
Large enterprises (LE)	64
Small and medium-sized enterprises (SMEs)	34
Unknown	2

*http://ec.europa.eu/enterprise/enterprise_policy/sme_definition/index_en.htm

The volume of studies in the areas of medicine and molecular biology is similar to the weight of these disciplines in Spanish scientific output (Moya-Anegón F et al., 2008), and to the pattern found in most industrialized countries, according to the SCImago Journal and Country Rank (SJR, 2009). The values for physiology and pharmacology, by contrast, are higher on both counts. The preponderance of pharmacological studies can be explained by the profile of the companies analyzed (Table 9). Moreover, the high productivity in biomedical areas confirms the sensitivity of such companies to knowledge transfer and their role as mediators between universities and the market (Audretsch DB and Stephan PE, 1996).

The geographic distribution shows that over half of the top 50 firms' papers are generated by Madrilenian companies, which account for 44 % of all the companies in the sub-set analyzed. From the standpoint of collaboration, however, while institutions in Madrid account for 61 % of the output, more Catalonian than Madrilenian institutions participate in joint projects. Valencian firms also make a substantial contribution, for while only 2 % of top 50 firms are located there, they account for more collaboration and production than the 6 % of organizations in the Basque Country, for instance (tables 3 and 4).

The overall analysis of the regional data corroborates the importance of geographic proximity in national collaboration. The findings for international collaboration likewise ratify the role of geographic proximity in the choice of partners. Nearly 90 % of the joint papers involve European partners and nine of the ten countries with the highest collaboration rates are in Western Europe (table 6).

Nonetheless, in both national and international collaboration, a strong relationship can be observed between partnering region/country and scientific and research importance that transcends geographic barriers. In other words, the choice of partners may be due to geographic proximity, but objective data show that such relations are based less on geography than on partners' importance and the expectations around the validity of joint results. By way of example, over 40 % of the joint papers were co-authored with institutions in the United States, where links are not due to proximity (table 5). The choice of an English partner, for instance, would be due less to country proximity than to the fact that it ranked second in total output between 1996 and 2007 (SJR, 2009). The same argument is applicable to Madrid and Catalonia as drivers of science in Spain (Chinchilla-Rodríguez Z, 2006), (Moya-Anegón F et al., 2008).

By sectors, health system-related institutions are companies' preferred partners, which is consistent with the profile of the companies analyzed and their area of specialization (table 7). While the volume of studies conducted with universities is not surprising, the number of such institutions collaboration with private enterprise is unexpectedly low, and even smaller than the number of non-top 50 participants. In this case, the choice of partners is clearly related to reputation, for companies ignore sectoral affinities when seeking collaboration.

With regard to the network analysis findings, Spearman coefficient values (Table 10) were found for the comparisons of clustering coefficient and two hybrid indicators with two bibliometric (number of documents and number of citations), and two structural (degree and betweenness) indicators.

Table 10. Spearman's rank correlation coefficient for simple and hybrid indicators

Indicator	Rank correlation
Clustering coefficient-Betweenness	0.666
Clustering coefficient-Citations	[a]0.387
Clustering coefficient-Degree	0.835
Clustering coefficient-Publications	[b]0.289
Clustering coefficient-Popularity index	0.754
Clustering coefficient-Prestige index	0.698
Popularity index- Betweenness	0.625
Popularity index-Citations	0.595

Popularity index-Degree	0.659
Popularity index-Publications	0.477
Prestige index- Betweenness	0.431
Prestige index-Citations	0.694
Prestige index-Degree	0.545
Prestige index-Publications	0.401
Popularity index-prestige index	0.888

p=0.0 except: [a]p=0.00001; [b]p=0.000034

The hybrid indicators emphasize not only the importance of the values furnished by traditional bibliometric indicators, but also the need for aggregates to have a prominent position from a structural standpoint. Therefore, much has to be gained from the differentiation proposed, whereby firms are evaluated based not only on absolute volume but also their importance in the network. The latter is defined in terms of their ability to draw and shape partners, highlighting the importance of collaboration in Science expressed with a model based on clustering coefficient.

The resulting values show that the lowest correlations are found for the variables constituting the hybrid indicators (clustering coefficient-ndoc and clustering coefficient-citations). Moreover, the correlation between ndoc and popularity index is scantly significant, statistically speaking. The dependence between citations and prestige index is higher. Moreover, the high correlation between the two hybrid indicators shows that in this case the most popular and most prestigious nodes largely concur.

Lastly, even though grid mapping led to the elimination of some of the original nodes, it is an excellent tool for reducing complexity, for it shows the central node of the top 50 companies that have interconnections. Of particular relevance is the function of the three intermediary institutions that support the main structure, forming the backbone of inter-company relations. The University of Salamanca (USAL) partners with nutrition and pharmacology companies. Madrid's Institute of Materials Science (ICCM) collaborates with engineering, energy and materials science companies, and the Institute of Biomedical Research of Barcelona (IDIBAPS) with pharmacology firms.

Light coloured nodes, i.e., pharmacological companies, predominate in the top 50 structural core. Companies with other business profiles are found in peripheral positions. Lilly, located at the centre of the diagram, participates in joint research with some of the most productive nodes in the sector, and also maintains links with the three non-top 50 intermediaries.

6. Conclusions

In the sub-set analyzed, the subject area distribution of the contribution of Spanish business by specialities was consistent with the overall nation-wide findings, except in the case of the pharmaceutical industry. This industry's high production is explicable in light of the make-up of the Top 50 firms, nearly 60 % of which are pharmaceutical companies. These results confirm similar findings that attribute the pharmaceutical industry a leading role in international scientific production in the pursuit of new knowledge (Calero C et al., 2007). This assertion is extensive to all other biomedical specialities, whose relative weight in the case analyzed is comparable to the proportion that their output represents in the total volume of scientific production in the major industrialized countries. Moreover, while private enterprise accounts for 30 % of the institutions participating in national scientific output, it authors only 3 % of the published papers. This is a reflection of the fact that 99 % of Spanish firms are SMEs

(Ministerio de Industria, 2009), and of the special social, political and economic features that characterize the Spanish private sector (Bayona C et al., 2001), (Segarra-Blasco A and Arauzo-Carod JM, 2008). In this regard, the findings show that output was low in 75 % of the collaborating Spanish firms, which produced a maximum of only three joint papers with international visibility in the period studied. It is hardly surprising, then, that most of the top 50 firms are large-scale companies, for such firms are traditionally better positioned to invest in R&D and consequently have a higher scientific output, confirming that the participation of large companies ensures the success of collaborative endeavours (Okamuro H, 2007).

Secondly, the choice of national and international partners, while often concurring with institutions that are geographically close, is based on merit and scientific importance endorsed by the significance of their research findings. This confirms that working with reputed partners contributes to the success of collaboration (Mora Valentín EM et al., 2004). Internationally, the predominance of the U.S. is related to that country's hegemony in biomedicine and pharmaceuticals (Miotti L and Sachwald F, 2003). A similar situation is observed on the domestic scale. Since a significant proportion of institutions are located in Madrid and Catalonia, these regions' output is high, but so is the proportion of joint research. The choice of partners, here also, is due less to geographic proximity than to these regions' leadership on the national scientific and technological arena (Sanz Menéndez L and Cruz-Castro L, 2005). As a rule, then, collaboration with other institutions is chosen not because of (geographic, political, social, cultural or any other type of) proximity, which would facilitate understanding, but because of interests, abilities and needs that contribute to solving common problems. In other words, this choice is based on cognitive proximity, which involves greater effort, but also generates higher benefits.

Thirdly, collaboration with the rest of the institutional sectors is in line with the absolute values for Spanish output as a whole, although two aspects stand out. On the one hand, the findings show a strong tendency to collaborate with universities. Of note in this respect is that while many studies are conducted jointly, only a small number of academic institutions are actually involved. This may be due to the fact that cooperative research projects are often funded by multinational firms, which have more generous resources from which to draw and a longer tradition of R&D investment. Spanish companies, in turn, are more dependent on public funding when undertaking such endeavours.

On the other hand, while a fairly large number of companies participates in the scientific output attributed to private enterprise, the number of papers produced is small. The former of these observations may be explained by businesses' frequent practice of funding joint projects with institutions of higher education, and the latter by the insurmountable barrier that market competition entails.

Fourthly, a number of interesting conclusions can be drawn from structural analysis. The enterprise network reveals the importance of pharmaceutical companies, not only because of their predominance, but also because of their structural position and intense partnering. While not the most productive, they occupy central positions in the network. This shows that collaboration is more fluent among institutions with the same business profile. Besides, one of the core ideas of this study is the emphasis on the essential role of collaboration in improving scientific results. The findings also provide proof of the success of strategies for institutional collaboration. The low correlation coefficients between the different variables indicate that the intensity of a company's collaboration is not contingent upon its output or visibility. Consequently, the predominance of an organization in a given indicator (production or visibility) is independent of its popularity or prestige index values. The foregoing shows that the application of hybrid indicators to institutional aggregates yields novel results not explored in preceding studies.

Another significant observation is the position held by several U.S. and European multinationals on the Spanish network. Subsequent research should ascertain their influence and the existence or otherwise of combined studies involving different areas in one and the same company. Such observations notwithstanding, the overall values of national (62 %) and international (28 %) collaboration would appear to indicate that the research conducted by these multinational companies is eminently local. From this perspective, the present paper corroborates the widespread idea, generally accepted within the international scientific community, to the effect that scientific partnering has beneficial effects, enhancing both productivity and visibility.

Lastly, a number of factors mentioned in the introduction but not covered here may constitute the object of future study. One might be the characteristics of collaboration by national enterprise, based on the analysis of patents, research agreements and publicly funded projects. Such studies could focus on a specific business profile or geographic area (Malo S and Geuna A, 2000), (McMillan GS et al., 2000). Another area of interest is company motivation when seeking partners, based on an analysis of national and international collaboration, and whether such motivation affects the quality of the results or partnering intensity. A third consideration would be the structural results of patent, research agreement and funded project networking, in particular as regards indicators referring both to centralization and each participant. Finally, trends would have to be analyzed to ascertain the structure of collaboration and the changes taking place over time, for both bibliometric and structural indicators are dependent upon the size of the time window defined.

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