Jointly published by Akadémiai Kiadó, Budapest
and Kluwer Academic Publishers, Dordrecht

Scientometrics,
Vol. 58, No. 2 (2003) 429–443

A Vector Space Model as a methodological approach to the Triple Helix dimensionality: A comparative study of Biology and Biomedicine Centres of two European National Research Councils from a Webometric view

JOSÉ LUIS ORTEGA PRIEGO

Cádiz Provincial Public Library, Jaén (Spain)

The aim of this paper is to propose a Vector Space Model as a new methodological approach which allows us to present the relationships between the elements of the Triple Helix Model (University, Industry, Government) in a spacial model by using the webpages of the National Research Councils of Germany and Spain as examples. Outlinks of the Biomedicine and Biology centres of these national councils were analysed with the intention of representing graphically these relationships through the Vector Space Model that allows for Multidimensional Scaling in three dimensions. Results show a map with the differences and similarities between the Spanish and German cases. It may be concluded that these results could become a qualitative_indicator of a scientific and technical reality.

Introduction

Nowadays it can be recognized that we are immersed in a knowledge-based society, in which the production of new knowledge is more and more essential for the economic machine. The main objective of the Sixth Framework Programme 2002-2006 of the European Union is to "create a Europe of knowledge and this clearly hinges on research and educational policy".[1] In other words, the knowledge generation is becoming an added value to the economy and the society of a region or country. It is possible to say that the greater the capacity a country has in producing knowledge, the more advantageous its position with respect to others, since knowledge allows us to improve our economic and social systems.

For these reasons, public administrations are increasingly involved in scientific policies through R+D and national research plans. Through them, they hope to locate

Received July 14, 2003

Address for correspondence:
JOSÉ LUIS ORTEGA PRIEGO
Internet Lab, CINDOC (CSIC), Joaquín Costa, 22, 28002 Madrid, Spain
E-mail: jortega@cindoc.csic.es

0138–9130/2003/US $ 20.00

their productive sector in the knowledge-based society and to obtain a competitive position with respect to others. These new policies imply a series of indicators that allow the evaluation of their evolution and operation, so that it is possible to justify the public and private investments made to reach this Knowledge-Based Society.

In the development of this knowledge-based society the convergence of three worlds has been observed: university, industry and government.[2] These three productive agents, tend to work together following a helicoidal model, with entailments that emerge at diverse levels of the innovation process, to form the so-called "triple helix".

Triple Helix Model

The Triple Helix Model was raised and developed by Etzkowitz and Leydesdorff,[3] who stressed the importance of developing policies which consider the importance of the relationships between the three different factors, industry, government and university.[4] Taking into account the present tendency to integrate the policies of science and technology within the context of the industrial policy, in a context of mixed economy and increasing international economic competition, this change in the way of understanding the policies has also affected the connections between these factors. They have adopted the roles of the other factors, for example, industries which conduct research, universities which managing companies, etc.[5]

Because of this, many studies have been devoted to the understanding of the institutional relationship between universities, industries, and governments from a web view. Leydesdorff and Curran[6] have studied the development of two national innovation systems (Brazil and the Netherlands) sending queries to the AltaVista search engine regarding Triple Helix terms ('university', 'government' and 'industry'). Boudourides[7] studied the institutional relationships under the Triple Helix from correspondence analysis. Currently, the WISER Work Group,[8] whose next objective is to construct Web indicators for scientific evaluation, is studying the co-links between industry, university and government.

In a recent study, Leydesdorff and Scharnhorst[9] brought up the dimensionality of the Triple Helix Model. In their opinion, the retrieval data according to the three agents of the model (no. of addresses in a scientific article, no. of out and inlinks in a Web domain, etc. which point to university, industry or government) "once categorized, [...] can be analysed by using the statistics of mutual information. The mutual information (or transmission) differs from co-variation, co-occurrence measures or correlation analysis because this measure is also defined in three dimensions". From my point of view, this dimensionality could also be studied with vector techniques from a webometric view.

Webometric Studies

Since Abraham[10,11] began webometric studies, important questions have arised regarding their methods and their same theoretical base.[12] In fact, it has been questioned whether the Web links can be used as bibliographic citation ("sitations")[13] as well as the use of the bibliometric techniques (Journal Impact Factor, Co-Citation Analysis, etc.) to the Web. The question is whether the cause of the Web links creation is the same as that of a bibliographic citation. From this point of view, Thelwall and Harries[14] find a strong relationship between incoming links of a university site and its scientific productivity. In a recent work, Wilkinson et. al.[15] proved that 90% of the university links are created for educational reasons.

If it is possible to consider that Web links are comparable to bibliographic citation, we can also consider the possibility of using the bibliometric tools for the webometric field. Almid and Igwersen[16] transferred the Journal Impact Factor of the bibliometry to the webometry under the name of the Web Impact Factor. This indicator shows us the visibility degree of a Web, although there are studies that question its validity.[17] Abraham[10,11] used co-citation analysis[18] to explore connectivity among California University Web sites. Larson's[19] work was also based on co-citation analysis to study Web site co-occurrences in Earth Science, mapping them through the MDS.

Object

The purpose of this paper is to present the Vector Space Model (VSM) as a new methodological proposal showing a spatial model of the Triple Helix relationships between National Research Councils and different agents from the model (University-Government-Industry) through their Web outlinks. The vector space is analyzed in terms of the cosines between the vectors.[20] The cosine relationships between three vectors can be mapped in a two-dimensional representation using a triangle with equal sides.

The study was limited to the Biology and Biomedice research centres, institutes or labs of two National Research Councils, the Max Planck Gesellschaft (MPG),[21] Germany and the Consejo Superior de Investigaciones Científicas (CSIC),[22] Spain.

Material and methods

Study field

The National Research Councils have been selected because they offer a view of the public research system, and give information on the scientific development stage in different countries, within the European scientific policies.

The Biological and Biomedical research fields which are currently the most dynamic and the greatest in social importance at this moment because of genetics, cloning, transgenic agriculture, etc., in addition to receiving the most important weight within the European Union research policies (Sixth Framework Programme, 2002–2006).

Finally, studying the reality of two European countries will enable us to approximate to the European research area. Spain is characterised by a relatively new public research system (one was not based until the eighties with the arrival of democracy) and a relatively small importance in European science, whereas Germany has a long tradition of public research and a prominent weight in European science. Both countries face regional research systems as a challenge in scientific dynamics.[23]

Software and tools

At the data retrieval stage, several tools were used. Firstly, for the Web site analysis of each centre a "spider", CiberSpyder Link Test 2.1.18,[24] was used for the extraction of outlinks. Secondly, information was taken from outlinks selected from a Microsoft Access 2000 database. Thirdly, to calculate the Vector Space algorithms a Microsoft Excel 2000 spreadsheet was used. And finally, the graphic display of the model through Multidimensional Scaling (MDS) was made with the statistical software ViSta: Visual Statistic System,[25] Forrest Young's freeware product.

Data

For the data retrieval process, accomplished during the months of October and November of 2002, the previously mentioned spider CyberSpyder Link Test was used. The use of the spider or crawler allows us more coherence than with search engines.[13]

I have focused my attention on certain *web servers at the level of sub-domains* or sdws.[7] The process was started from web sites of each centre and at the first stage 65,625 links were obtained, of which 51,229 (79%) were eliminated for reasons to be specified below. Thus, 14,396 links were accepted, of which 2,807 (19,5%) were national outlinks. Finally, the study was developed with 396 national links for the Spanish National Research Council and 2,411 for the German. The selection criteria of accepted links was:

- Links which referred only to (.es) or (.de), except for (.com) and (.net) in cases where these links belonged to both countries.
- Links to different servers, although they formed part of the same sub-domain, e.g. cajal.csic.es point to cib.csic.es.
- Links to textual formats (HTML, txt, pdf, ps). Other links that were eliminated, included "mailto:" and "javascript:"
- Links to resources exclusively related to the Biology and Biomedicine field (Links to travel agencies, public transport, etc. were frequently found.)
- Links to services and companies that develop specific products for research in general (computer companies) or are specialists in Biology and Biomedicine. Web Statistics services (e.g., Netstat) and companies that commercialize products for the reading of a certain type of Web format were also eliminated (e.g., Macromedia, Adobe, WinZip, etc.).
- Links to resources of specialized information such as genetic data bases, (e.g., The Genome Database) and specialized information centres (National Medicine Library). Links to generalist search engines and portals were eliminated (e.g., Google, Yahoo, etc.).

Once the valid links had been selected, the total number of national outlinks were arranged into the three categories, university, industry and government, in percentual form. These three categories allow further development of the Triple Helix Model. The arrangement criteria was:

- For government: all the outlinks to local or national government organisms and all type of centres which have public entitlement or have been created and financed by public institutions.
- For industry: all the outlinks to private or non-profitable organisations or those of an economic or commercial character. Within this scope publishers and their scientific publications were found.
- For university: all the outlinks to any unit or department of a university, including dependent research centres of universities and resources or projects within these.

In some cases a double category was assigned to established resources of joint form by different elements from the model; joint research projects between university and government have been assigned to them.

Vector Space Model (VSM)

The vector space model[26] (VSM) considers a distribution (variable) as a vector. Between two vectors one can compute a cosine that varies from 0 to 1. This measure was used by Salton[27] in information retrieval field. The Biblometric technique was used by Ortega[28] and raised by Larsen and Igwersen.[29]

The VSM allows us to describe any object with many characteristics in a gradual form. Thus, a vector (V_1={F_i, F_j..., F_n })is characterized by the (*f*) frequency of occurrences that it has in the characteristics ($_{i, j.., n}$).

	i	***j***	***N***
V_1	F_i	F_j	F_n
V_2	F_i	F_j	F_n

Through a scalar calculation, one obtains the similarity degree of different vectors using the following formula:[28]

$$S(V_1\ ,V_2\ ) = \frac{\sum F_1 F_2}{\sqrt{\sum F_1^2 \sum F_2^2}}$$

The VSM can compare two vectors from its multiple occurrences, and not from its co-occurrences as happens with Co-Citation Analysis.[18,30] The VSM is not based on co-occurrences which is the reason why it does not need a third item, like the Co-Citation Analysis, that expresses the relationship between two items. Finally, the VSM enables us to define *factitious vectors* that help to explain and to understand where these items are located in a space model (e. g., Multidimensional Scaling). On the contrary, the Co-Citation Analysis – based on cooccurrence counts – does not allow us to locate reference items in a spatial model. While the Co-Citation Analysis is a relational model, the VSM is a positioning model.

For this study, the Web sites were converted into vectors and the elements of the Triple Helix (university, government and industry) the characteristics where the outlinks that arise from the Web sites have been classified. The links percentage that point to registered Web sites in these three characteristics will give its position in the spatial model. For example, the MPI of Biochemistry vector would be:

	Industry	Government	University
MPI Biochemistry	0.126263	0.459596	0.414142

We can see that 13% of the outlinks point to industrial Web sites, 46% to administrative sites and 41% to university sites. The next step was to add to the model four *factitious vectors*: Government (G={1,0,0 }); Industry (I={0,1,0 }); University (U={0,0,1 }) and an intermediate vector between the three IGU (IGU={0.5, 0.5, 0.5 }). These vectors will serve as reference frame to explain the results, in topographic terms, they would be geodesic points.

Through the equation previously described, the similarity of the vectors of the research centres with vectors G, I and U (vector IGU was used as a reference point to explain the resulting model) were obtained. Finally, the obtained similarities were transformed into distances (D_i=1-S_i). The final result is an asymmetric matrix of distances of 37x3 for the German centres and another asymmetric matrix of distances of 22x3 for the Spanish centres. These matrices appear in the Appendix.

Multidimensional Scaling (MDS)

Multidimensional scaling (MDS) "is a set of data analysis techniques that display the structure of distance-like data as a geometrical picture".[31] Its origin is in the studies of Torgerson[32] on metric MDS and Kruskal on non-metric MDS.[33] By means of this algorithm a vector space from *n*-dimensions is displayed in a 2 or 3 dimensional graph, allowing the graphical representation of these vectors and locating its position in the space.

In this case, the non-metric MDS was used because the VSM allows us to obtain a non-symmetrical matrix, unlike the Co-Citation Analysis that always produces a symmetrical co-occurrence or (normalized) similarity matrix. On the other hand, two matrices with just three distances provide a stress value (φ=0), so that the fitting of the model can be considered exact.

Results

The result of the graphical display shows a Stress value (φ=0) for the three-dimensional model. The results of each National Research Council MDS graph are discussed below.

Consejo Superior de Investigaciones Científicas (CSIC)

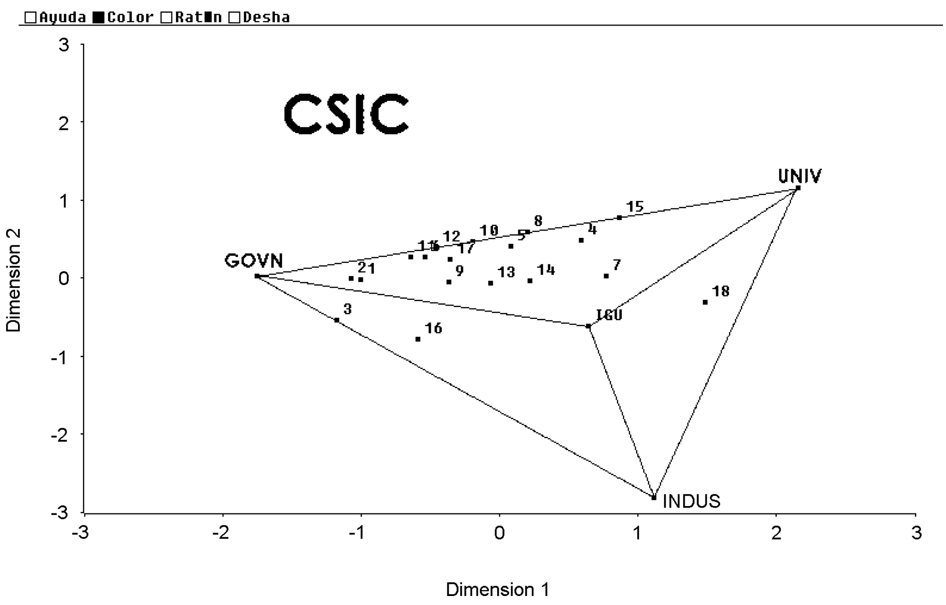

Figure 1. The MDS map of the Consejo Superior de Investigaciones Científicas Biology and Biomedicine institutes

In this first map, produced by the Biology and Biomedicine centres of the CSIC, we can perceive that most of the centres are very near to the government-university axis. Only a few centres are directed fowards the industry vector through the IGU vector, the gravity centre of the model. This coming together is so slight that it can hardly be said to be a part of the model nucleus. This illustrates the strong independence of these centres with respect to the Industry vector, which demonstrates a small weight of the industrial sector in the relationships of the CSIC centres. For this reason, the gravity centre of the Triple Helix Model, the zone around vector IGU, is isolated, without the presence of centres, so it could be assumed that these centres do not fit into the Triple Helix Model, since the connections between the government and the university are solely bilateral. This fact can be explained because many of the centres are affiliated to universities.

As an example of an exception, let me point out the case of the centres 3 and 16 that they come near to a government-industry relationship. Note also the case of point 18 (Biophysic Unit, centre assigned to The University of the Basque Country) which has a larger dependency on the university, and simultaneously comes near to the industrial sector, but in this case to regional industry.

But in none of the previous cases even a slight sign of triple relationship has been detected, that would allow us to find a situation of national innovation system. To detect this relationship, they would have to come near to the vector IGU zone.

Max Planck Gesellschaft (MPG)

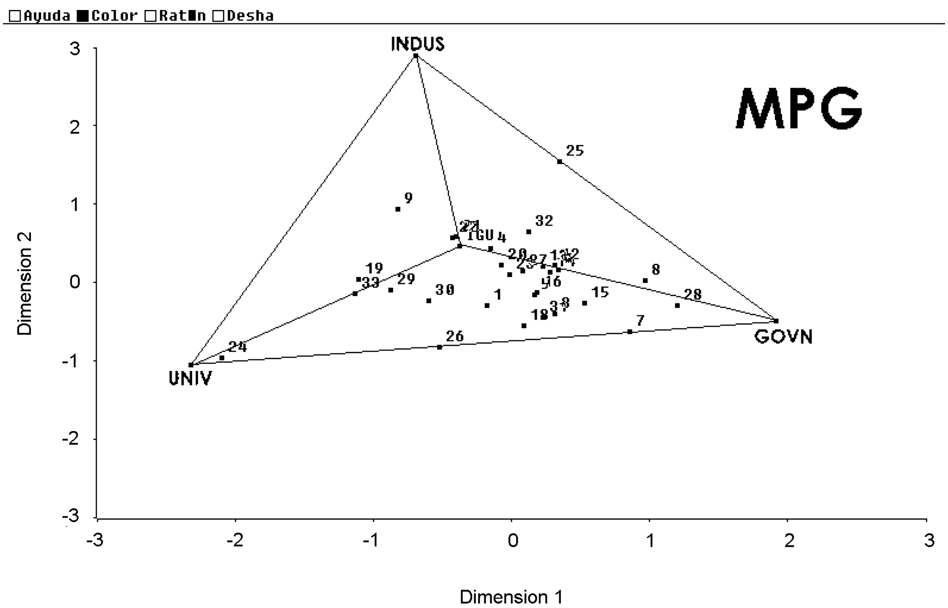

Figure 2. The MDS map of the Max Planck Gesellschaft Biology and Biomedicine institutes

On the contrary, in the model produced by the Biology and Biomedicine centres of the Max Planck Gesellschaft a greater scattering of centres between the three axes was found, although a greater percentage of points were located in the government axe. But unlike the Spanish model, the German centres come more obviously closer to the central vector IGU. These results suggest that, in the German case there is a greater tendency towards the Triple Helix Model, because the three axes of the model draw these centres towards a central intermediate position, demonstrating a clear intervention of the three agents of the model.

As in the Spanish case, the centres assigned to the universities tend to be located nearer to the university than the government. A good example is the point 24 (MPI for Terrestrial Microbiology, Marburg) which is located next to the University because this is a Univ. of Marburg affiliated centre. Although it is certain that this tendency, more pronounced in the Spanish case than the German, may be caused by the affiliated centres to the universities. In this situation, the MPG has only one assigned centre, whereas the CSIC has seven.

On the other hand, two centres, numbers 9 and 25, are those that are pulled closer to the Industry vector. Maybe, this fact is produced because both centres work in the Bioinformatic field and they need technological tools provided by the industry.

Conclusions

The use of a vector space model has allowed the webometric data analysis from a different point of view. This technique, unlike others, has allowed the study of differences and the similarities of vectors from the values that they adopt from manifold variants, in this case the outlinks that point to Government, University and Industry Web sites. Through this, it is possible to concluded that this methodology is a valid tool for the study of the Triple Helix, since this model needs methodologies that study the relationship of Triple Helix elements. The use of the Multidimensional Scaling has been a good aid in presenting the resulting model in graphical form, since this visualization method has allowed the positioning of these research centres.

Apart from this, these tools comed also be used for the design of qualitative indicators. The VSM provides as an important tool to solve the complexity of the relationships that emerge in an innovation system, not only for the study of the socioeconomic reality of a place but also for the planning of policies related to Research and Development. In this sense, the SIBIS[34] and WISER[8] projects are a good example. The Maps of Science[35] also are a good example of this search for qualitative indicators based on the power of the graphical representations and they are also a form of understanding a complex reality like in the scientific world. Aguillo y Pareja conclude:[36] "Relationship with other sectors are easily uncovered using link analysis, so it is suggested the use of new visualisation tools based on multidimensional techniques to increase our knowledge of the innovation processes is suggested".

On the other hand, it can be concluded that the outlinks analysis has allowed us to provide information on the behaviour of these centres at the moment of creating links and, in turn, to describe the environment where they are located. Although it is true, that not all the outlinks are representative of the activities and objectives of the Web sites that create them, as with 79% of the links excluded. The use of a *crawler* or *spider* has allowed us to obtain a large number of links directly from Web sites, excluding the bias that arises from search engines. The use of these tools would improve the webometric results and although it is necessary to realise that its treatment is more complex and difficult. For this methodologic proposal this is the most suitable tool.

Finally, the flexibility of this methodology enables us to study Web links from multiple points of view. For example, a geographic approach, allows us to see the transnational relationship of science; or from a thematic point of view, we can appreciate the emergence of new research fronts. In this way, it is desired that this new methodologic proposal helps to support the webometry as a emergent research field, at the same time that it makes it possible to look deeply into the study of the Triple Helix Model.

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The referees are warmly thanked for their helpful comments.

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Appendix
Vector distances matrix of Max Planck Gesellschaft Research Centres with the Triple Helix Model agents

	Max Planck Gesellschaft Research Centres	Industry	Government	University
1	MPI of Biochemistry	0.87373737	0.54040404	0.58585859
2	MPI of Biology	1	0	1
3	MPI of Biophysics	0.92248062	0.41085271	0.66666667
4	MPI for Biophysical Chemistry (Karl Fr. Bonhoeffer	0.68073879	0.6121372	0.70712401
5	MPI for Brain Research	0	0	0
6	MPI for Behavioral Physiology	0.85294118	0.47058824	0.67647059
7	MPI for Plant Breeding Research	0.77083333	0.45833333	0.77083333
8	MPI of Vascular Biology	1	0.25	0.75
9	MPI for Biological Cybernetics	0.83333333	0.29166667	0.875
10	MPI of Chemical Ecology	0.51807229	0.8313253	0.65060241
11	MPI for Cell Biology	1	1	0
12	MPI of Molecular Cell Biology and Genetics	1	0	1
13	MPI for Developmental Biology	0.75247525	0.47524752	0.77227723
14	MPI of Experimental Endocrinology	0.72727273	0.54545455	0.72727273
15	Max Planck Research Unit for Enzymology of Protein	0.77272727	0.47272727	0.75454545
16	MPI for Experimental Medicine	0.88888889	0.37037037	0.74074074
17	The Friedrich-Miescher-Laboratory of the MPG	0.84444444	0.46666667	0.68888889
18	MPI for Molecular Genetics	1	0	1
19	MPI of Immunobiology	0.95	0.45	0.6
20	MPI for Infection Biology	0.75144509	0.80924855	0.43930636
21	MPI for Limnology	0.73770492	0.57377049	0.68852459
22	MPI for Medical Research	0.63235294	0.69117647	0.67647059
23	MPI for Marine Microbiology	0.77018634	0.54037267	0.68944099
24	MPI for Terrestrial Microbiology	0.98347107	0.95041322	0.0661157
25	MP Working Group for Structural Molecularbiology am	0.4	0.6	1
26	MPI of Neurobiology	1	0.57142857	0.42857143
27	MPI for Neurological Research	0.76271186	0.52542373	0.71186441
28	Max Planck Research Centre for Ornithology	0.92	0.2	0.88
29	MPI of Molecular Plant Physiology	0.79591837	0.73469388	0.46938776
30	MPI of Molecular Physiology	0.84375	0.65625	0.5
31	MPI for Physiological and Clinical Research	0.92857143	0.42857143	0.64285714
32	MPI of Psychiatry	0.63333333	0.56666667	0.8
33	MPI for Psycholinguistics	0.7962963	0.7962963	0.40740741
INDUS	**Industry**	0	1	1
GOVN	**Government**	1	0	1
UNIV	**University**	1	1	0
IGU	**Industry-Government-University**	0.5	0.5	0.5

Vector distances matrix of Consejo Superior de Investigaciones Científicas Research Centres with the Triple Helix Model agents

	Consejo Superior de Investigaciones Científicas Research Centres	Industry	Government	University
1	Molecular Biology Centre "Severo Ochoa"	0.92857143	0.21428571	0.85714286
2	Research and Development Centre	0.93548387	0.19354839	0.87096774
3	Biological Research Centre	0.8	0.2	1
4	National Centre of Biotechnology	0.94444444	0.61111111	0.44444444
5	Molecular Biology Institute of Barcelona	0.96296296	0.48148148	0.55555556
6	Plants Molecular and Celular Biology Institute " Primo Yufera"	0.96774194	0.32258065	0.70967742
7	Cancer Molecular and Celular Biology Institute	0.8	0.7	0.5
8	Biology and Molecular Genetic Institute	1	0.5	0.5
9	Biomedicine Institute of Valencia	0.86842105	0.39473684	0.73684211
10	Biochemical Institute	1	0.4	0.6
11	Vegetal Biochemical and Photosynthesis	0.97777778	0.28888889	0.73333333
12	Pharmacology and Toxicology Institute	1	0.33333333	0.66666667
13	Biomedicine Research Institute "Alberto Sols"	0.84210526	0.47368421	0.68421053
14	Biomedical Research Institute of Barcelona	0.83333333	0.54761905	0.61904762
15	Biochemistry Microbiology Institute	1	0.66666667	0.33333333
16	Neurobiology Institute "Ramón y Cajal"	0.69047619	0.38095238	0.92857143
17	Parasitology and Biomedicine Institute "López Neyra"	0.94736842	0.36842105	0.68421053
18	Biophysic Unit	0.625	0.5	0.875
INDUS	**Industry**	0	1	1
GOVN	**Government**	1	0	1
UNIV	**University**	1	1	0
IGU	**Industry-Government-University**	0.5	0.5	0.5