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# Scientific network and performance of human resources: Evidence from Italian University in Chemistry field

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**Abstract**

The paper investigates the role of scientific network in knowledge production in chemistry field for the Italian Universities, considering the models of research and teaching evaluation, the intangibles report and the network analysis approach. The analysis shows relevant correlations between the features of network, scientific performance of human resources in teaching and research processes and provides an overview of Italian Universities activity within the knowledge production in Chemistry. The study utilizes a multidimensional statistical analysis and considers the Italian academic researchers, taken from 2001 to 2007, in Chemistry field, chosen for its particular relevance for bibliometric indicators.


*Keywords:* Scientific network; human capital; scientific performance; intangible activity evaluation; university management.

## 1. Introduction

Italian universities are involved in a changing process that enhances both the competition and the cooperation, through the mechanisms of allocation of financial resources and through greater international comparison of scientific performance. Given the intense competition, universities are increasingly recognizing the necessity and advantages of regularly developing scientific collaborations.

General studies have shown that the collaborations, especially international ones, improve the scientific performance of the human resources, the productivity and the visibility of university, through the knowledge sharing among the members of academic groups. The measument of these effects is based mainly on the bibliometric indicators, which are considered objective and able to improve comparability among organizations (Katz & Martin, 1997). Therefore an exclusive and uncritical use of these measures penalizes certain scientific categories in which the scientific output is not a journal article. As a consequence, international research policies suggest the adoption of measurement tools, qualitative and quantitative, of these intangibles resources within the universities, the educational institutions and research centres (OEU, 2006), in order to promote the trasparency in the use of public funds and the results produced by research and educational activity and, then, to address the decision-making process. These institutions present complexity due to the presence of heterogeneous structures, decentralized

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decision-making bodies, many informal relationships among research teams and a conjunction between teaching and research processes, which use the same resources (Knight, 1987). Criticism is mounting on hard science for their excessive focus on researching and the relative neglect of teaching quality. However, when employment and growth declining, the investment in human capital acquired through education should matter at least as much as the advance in technology or management brought about by research. Thus, if public investment promote the research and penalize the education quality, the final outcome can be socially sub-optimal.

Using a relational perspective, we argue that human resources' performance in these insititutions is related to their degree of centrality within the scientific network. We test our hypoteses within Chemistry field, through a quantitative methodology and investigating the role of scientific network in knowledge production in, considering the models of research evaluation, the intangibles report and the network analysis approach. The study considers financial and qualitative data, concerning human and organizational resources, of 6 Italian Universities and 732 Italian researchers on Chemistry, using a bibliometric-type approach in which collaboration and co-authorship are treated on a par. It also try to establish what dimensions of network are connected with the scholarship and the international openess.

## 2. Literature review and research hypotheses

Italian Universities are tipically professional structure, in which the professors respresent the main operational part of structure, with and heavy technical and administrative component. In these insititutions the researchears (professors and researchers) are employeed both in research and in teaching activity and they are fundamental for the success of university in creating knowledge, professionalism, social development and economic growth. One particular means by which researchers acquire and deploy their skills and knowledge is the scientific collaboration. Sociologists have shown that informal network ties can be just as important to the acquisition and trasmission of scientific knowledge (Nelson & Nelson, 2002; Balconi, 2002).

While most research on this topic focuses on the linkage between research collaborations and the productivity of human resources (De Solla Price & Beaver, 1966; Frame & Carpenter, 1979; Van Raan, 1998; Adams et al., 2005; Lee & Bozeman, 2005), others authors have studied the impact of collaborative networks on costs and visibility (Landry & Amara, 1998, Rigby & Edler, 2005), on technology transfer activity of the university (Bozeman & Boardman, 2003), on the scientific behaviour at individual-level (Boardman & Corley, 2008). Other studies emphasize the importance of intangibles report to improve the performance of these institutions (Bueno, 2002; Leitner, 2004; Sanchez & Elena, 2006) and the correlations between the knowledge sharing among the teaching staff and the student performance (Teddlie & Reynolds, 2000).

In Italian Universities the changing process initiated in the 90's with the regulation of financial autonomy has established new mechanisms of resources allocation performance-based and new evaluation methods inherent to such autonomy. As a consequence, the national government has supported several programs of research and teaching evaluation, including the first Research Assessment Exercise (VTR), carried out at Italian Committee for Research Evaluation [CIVR, 2006], ended in 2005. It was based on peer review of 18,508 scientific products from all scientific areas of years 2001-03, self-selected by the Universities and the national research institutions. Other experiences of research and teaching evaluation, reported at different levels (universities, departments, scientific staff), show a significant relationship with the models of intangibles reporting, generating intense scientific debate (Leitner, 2004, OEU, 2006). As far as the analysis of the drivers of research and teaching activities, some authors note the impact on productivity of scientific researchers produced by the following variables: the size and the prestige [Carayol and Matt, 2004], policies adopted by the organizations [Cole and Cole, 1973]; researcher's age and gender [Zuckerman and Merton, 1972; Stephan, 1998], training [Garcia-Romero and Modrego, 2001], the researcher's life cycle [Levin and Stephan, 1991; Rauber and Ursprung, 2006] and the teaching load [Fox, 1992]. The bibliometrics methods are controversial and, when judging the productivity of human capital, they fail to consider the relations vis-à-vis assessment processes [Adams and Griliches, 1998; Fayl 2001]. Also the degree of internationalization of knowledge is the subject of several studies [Van der Meulen, 2002; Hakala et al., 2004], which defined it both as the degree of product placement in international journals, whose importance is measured by impact factor, and also as collaboration with international research units or foreign co-authors.

The nature of collaborations allows appreciate the ability of universities to establish profitable relationships with public-private social partners, to attract and retain students, researchers and resources, to create a positive institution's image in rewarding social and scientific communities and facilitates several job opportunities for the students.

Collaborations are intangible resources but the universities can only govern the preconditions that ensure their repeatability and their consolidation, taking ownership of some results of cooperation (publications, funding) and the availability of benefits derived from them (visibility and quality of human resources, confidence, opportunities for science development, higher level of teaching). Scientific collaborations can assume several configurations: exchange of students and researchers among structures; joint development of research projects; organization of events to promote knowledge in the community science; contacts and meetings. Therefore, the more appropriate manifestation of these resources is given by the scientific publication, in which the presence of co-authors shows only the existance of formal groups, but it is not possible to define the boundaries of informal ones. The first studies on scientific collaborations showed a correlation between the international relationships and these variables: experimental nature of research project; national scientific system limited; citations. However, the increased visibility associated with co-authorships is not necessarily correlate with a higher quality of results and of researchers.

Recent studies explore the impact of characteristics of networks on individual performance through the variables derived by social network analysis (SNA). This methodology allows to identify groups, to measure the attributes, providing a valuable support in terms of management. In a specific relational context, composed of units defined nodes (or actors), SNA investigates the interactions that connect these units. According to the theorists of SNA (Scott, 2000; Wagner & Leidesdorff, 2005) is significant considering also the interactions among the members of a group, since these variables are responsible for a specific behaviour and decision-making process. Moreover, some authors argue that researchers located at the centre of these networks are more likely to identify attractive project-opportunitites because they have a better sense of the options available within the field (Ferriani et al, 2008). This approach, entirely consistent with the systems theory, can represent the appropriate conceptual framework to investigate the impact of collaborations (intangible resources) on research and teaching (intangible activity) into the hard science, in order to define useful approaches to manage these processes.

## 3. Research setting

To test our hypotheses we have chosen a specific field of science, Chemistry, in which the 93% of scientific output selected for the national research evaluation (VTR, 2001-2003) is a journal articles. This choice comes from the observation that in this field the journal article is the main vehicle for the knowledge diffusion in scientific community and this is confirmed by information acquired through eminent experts in this field.

We have selected a sample of researchers whose affiliation is present in 2,500 scientific products (articles, proceedings, reviews, etc..) on Scopus database in the period 2001-2007 and the entire scientific output of these researchers published in 2001. This year has been chosen to correlate the bibliometric indicators with the results of VTR and then to leave a time of exposure broad enough to consider the citations meaningful.

The resulting sample is composed as follow: 6 universities (Bologna, Milan, Naples "Federico II", Roma "La Sapienza", Torino); 732 researchers; 29.593 scientific products. Table 1 shows the variables observed.

In order to identify the relationships between the attributes of the network and other variables through which one studies the intangible activities of universities, analysis has been conducted on three levels:

- first level: all available information on relationships have been taken into account, then each product sharing has been seen as a collaboration between the actors and there is no "dichotomy" on the degree of intensity of collaboration (at this level the intensity of the relationship varies therefore between 0, no product shared, and the maximum number of products shared among researchers in the sample) (Figure 1);

- second level: we have transformed the intensity of collaboration in a dichotomous variable (1 / 0) through a level of cut-off placed at least 3 products sharing (i.e. below 3 shared products, there is no collaboration, since and over 3 products the collaboration retains the same intensity) (Figure 2);

- third level: we have used a level of cut-off placed at least 5 products shared (Figure 3)

Data have been subjected to bivariate correlation analysis and for categorical variables we have estimated a random variables, Pearson Chi-Square coefficient, to verify if the null hypothesis is probabilistically consistent with the data.

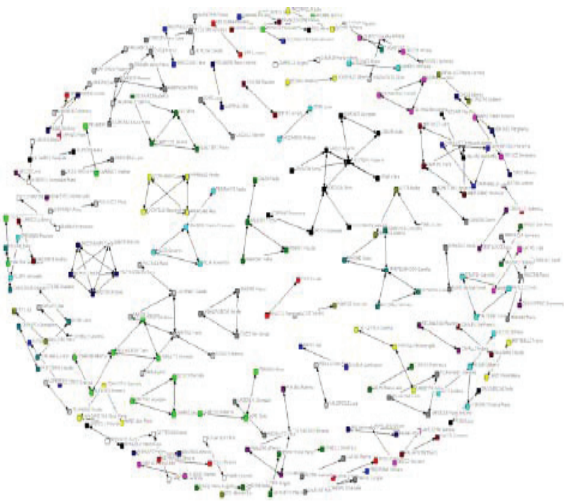

Figure 2. Network at second level (at least 3 joint products)

Figure 1. Network at First level of analysis

Figure 3. Network at third level (at least 5 joint products)

Table 1. Quantitative variables and categorical variables

| Resources source | Variables/ categorical variables | Description | Data |
|---|---|---|---|
| Human capital | Author gender | | MIUR |
| | SSD | Scientific disciplinary field | MIUR |
| | Professional Degree | Degree at 31/12/2001 | MIUR |
| | Horizontal mobility | Number of external transfer within Italian university system (2000-2007) | Our elaborations |
| | Vertical mobility | Number of career advancement within Italian university system (2000-2007) | Our elaborations |
| | Turnover | Recruitment and retirement for each University (2000-07) | Our elaborations VTR2001-03 |

| | | | |
|---|---|---|---|
| | NRicFTE | Number of researcher full time equivalent | VTR2001-03 |
| | NNRicFTE | Var. NRicFTE ranked on 4 level | |
| | RicInFormazioneRicETP | Number of scholarships, Phd, post docs.. | |
| Organizational capital | FinRicercaDaMIURRicFTE | Public funding for research projects in Chemistry | VTR2001-03 |
| | FinRicercaDaOrganIntliRicFTE | Funding for research projects in Chemistry acquired by international bodies | VTR2001-03 |
| | FinRicercaDaAutofinanziamRicFTE | Funding for research projects in Chemistry self-funded | VTR2001-03 |
| | FinRicercaDaAltriRicFTE | Funding for research projects in Chemistry acquired by Others | VTR2001-03 |
| | TotEntrateAteneo200103 | Total financial resources of the University (2001-03) | VTR2001-03 |
| | InvestimentiAteneo200103 | Total Investments of the University (2001-03) | VTR2001-03 |
| | EntrateAteneoDaTrasfCorr200103 | Total finacial resources acquired by governmental current transfers (01-03) | VTR2001-03 |
| | PersonaleTARicFTE | Administrative and technical staff / No. Researchers FTE | VTR2001-03 |
| | CaricoDidatticoPerAteneo | Teaching load in Chemistry field for each University | Our elaborations |
| | NCaricoDidatticoPerAteneo | Teaching load ranked on 4 levels | |
| Scientific performance – University level | RatingVTR200103 | Performance rating defined for chemistry field for each university | VTR2001-03 |
| | ProdottiPesatiVTR200103 | Number of weighted products (No.products/No.authors) | VTR2001-03 |
| | GiudiziDiMeritoEVTR0103 | Share of excellent product in Chemistry for each university | VTR2001-03 |
| | GradoDiProprietàDeiProdotti | Ownership ratio (No. authors who relate to the structure/total number of authors) | VTR2001-03 |
| | GradoDiProprietàDeiProdottiEVTR010 3 | Ownership ratio of excellent products | VTR2001-03 |
| | MediaIFProdottiVTR200103 | Mean of Impact factor (overall scientific products in Chemistry for each University) | VTR2001-03 |
| Scientific performance – individual level (researcher in Chemistry) | NProdottiPerAutore | Number of products for each author | Our elaborations on SCOPUS dataset |
| | NNProdotttiPerRic | Number of products for each researcher | |
| | TotCitPerAutore | Citations for each author (products published in 2001) | |
| | NTotCitPerRic | Citation for each researcher (ranked on 4 levels) | |
| | MediaCitPerProdottoPerAuto re | Average number of citations for each product and for each author | |
| | NMediaCitPerProdPerRic | Average number of citations for each product and for each researcher | |
| | MaxCitPerProdPerAutore | Maximum number of citations for each product for each author | |
| | NMaxCitPerProdPerRic | Maximum number of citations for each product for each researher | |
| Relational capital | RicInMobIntleRicETP | No. Researchers FTE in international mobility in Chemistry field (for each University) | VTR2001-03 |
| Network attribute | ComponentSize(All,GT2,GT4) | No. Researchers in the network (first level, second level, third level) | Our elaborations on SCOPUS and MIUR dataset |
| | Degree(All,GT2,GT4) | Degree for each researcher | |
| | Betweenness(All,GT2,GT4) | Betweennees (centrality measure) for each researcher | |
| | Closeness(All,GT",GT4) | Closeness (centrality measure) for each researcher within each network | |
| | HarmonicCloseness(All,GT2,GT4) | Centrality index for each researcher within each network | |

## 4. Results and discussion

Table 2 shows the correlation matrix between the attributes of scientific team (belonging to the network and measures of centrality) and other variables considered in the measurement of intangible resources (human, organizational and relational capital).

The analysis has been conducted on three levels chosen for the definition of the network, no exceptions, so as to identify, among other things, the level of aggregation more significant for the scientific area under consideration. The results can be summarized as follows:

- the size of network (ComponentSize) is positively correlated to these variables: number of researchers in training (Phd students, etc..); number of researchers in international mobility; funding for research projects from Other sources (fall into this category the research contracts); number of products of each researcher, number of citations (for each researcher), teaching load;
- the degree centrality is positively correlated to these variables: number of researchers in international mobility; number of products of each researcher; number of citations (for each researcher);
- the betweenness centrality is positively correlated to: number of products of each researcher; number of citations (for each researcher);
- the closeness centrality is positively correlated to: number of researchers in training; number of researchers in international mobility; funding for research projects from other sources; VTR rating and the related variable of the average IF of the products presented in VTR2001-03; number of products of each researcher; number of citations (for each researcher); teaching load;
- the harmonic closeness centrality shows significant correlation to the same variables related to Closeness albeit at a different level of analysis.

The analysis identifies a positive relationship between the teaching load (for each researcher) and Phd students, probably for their major involvement in teaching activity; hence it is useful detect significant correlations of this important factor with the others considered in the analysis.

Table 2. Correlation matrix

| | | RicInFormazione/RicETP | RicInMobIntle/RicETP | FinRicercaDaAltri/RicFTE | RatingVTR2001-03 | MediaIFProdottiVTR2001-03 | NProdottiPerAutore | TotCitPerAutore | CaricoDidatticoPerAteneo | N. relazioni significative e rilevan |
|---|---|---|---|---|---|---|---|---|---|---|
| ComponentSizeAll | P.C. | | | | | | | | | - |
| | Sig. | | | | | | | | | |
| DegreeAll | P.C. | | 0,201 | | | | 0,246 | | | 3 |
| | Sig. | | 0,000 | | | | 0,000 | | | |
| BetweennessAll | P.C. | | | | | | | | | - |
| | Sig. | | | | | | | | | |
| ClosenessAll | P.C. | | | | | | | | | - |
| | Sig. | | | | | | | | | |
| HarmonicClosenessAll | P.C. | | | | | | | | | 1 |
| | Sig. | | | | | | | | | |
| ComponentSizeGT2 | P.C. | 0,200 | 0,215 | 0,212 | | | 0,238 | 0,212 | 0,202 | 7 |
| | Sig. | 0,000 | 0,000 | 0,000 | | | 0,000 | 0,000 | 0,000 | |
| DegreeGT2 | P.C. | | | | | | 0,323 | 0,236 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| BetweennessGT2 | P.C. | | | | | | 0,240 | 0,210 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| ClosenessGT2 | P.C. | | 0,252 | | | | | | 0,244 | 3 |
| | Sig. | | 0,000 | | | | | | 0,000 | |
| HarmonicClosenessGT2 | P.C. | 0,207 | | 0,212 | | | 0,292 | 0,237 | | 4 |
| | Sig. | 0,000 | | 0,000 | | | 0,000 | 0,000 | | |
| ComponentSizeGT4 | P.C. | | | | | | 0,347 | 0,337 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| DegreeGT4 | P.C. | | | | | | 0,324 | 0,293 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| BetweennessGT4 | P.C. | | | | | | 0,350 | 0,423 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| ClosenessGT4 | P.C. | 0,209 | | 0,208 | 0,204 | 0,201 | 0,358 | 0,369 | | 7 |
| | Sig. | 0,000 | | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | | |
| HarmonicClosenessGT4 | P.C. | | | | | | 0,337 | 0,317 | | 2 |
| | Sig. | | | | | | 0,000 | 0,000 | | |
| **N. Relazioni significative e rilevanti** | | 6 | 6 | 6 | 2 | 2 | 20 | 18 | 4 | |

P.C. Pearson Correlation
Sig. Sig. (2-tailed)

Must emphasize the positive correlations and particularly relevant with some variables that share a direct correlation with the size and closeness of network (international mobility of researchers: correlation 0.868 with sig. 0.000; Phd students: correlation 0.338 with sig. 0.000).

It must therefore consider the hypothesis that the centrality of researcher within the network facilitates international openess, particularly the researcher mobility, and attracting new researchers to training, thus, the teaching load presents a correlation of reflection (in as related to the same indicators). The variables most frequently correlated to the attributes of scientific network are those related to performance individual researchers (number of products and total number of citations for each author), respectively with 20 and 18 significant relations identified. Consequently, it's shown that individual performance depends greatly on the degree of centrality recruited by the researcher within the network.

The attributes that have shown more frequent and meaningful relations with intangible resources are the Closeness Centrality (10 significant relationships at different levels) and size of the network (9 significant relationships at different levels). The level that showed the greatest number of significant relationships is second (at least 3 joint publications in one year) with 17 significant relationships; this confirming what we had been shown in preliminary interviews with the experts. Pearson Testing has provided the additional results illustrated in table 2 (the only significant relationships are reported and whose sign is easy reading) and figure 4.

The categorical variable "membership of scientific network" is positively associated with these variables:

1: scientific productivity of each author [Pearson Chi-Square: 60,080; df: 3; Asymp. Sig. (2-sided): ,000];

2: citations by author [Pearson Chi-Square: 60,024; df: 3; Asymp. Sig. (2-sided): ,000];

3: average number of citations by author [Pearson Chi-Square: 22,626; df: 3; Asymp. Sig. (2-sided): ,000];

4: maximum number of citations for each product received by each author [Pearson Chi-Square: 21,329; df: 3; Asymp. Sig. (2-sided): ,000];

5: vertical mobility [Pearson Chi-Square: 28,854; df: 3; Asymp. Sig. (2-sided): ,000].

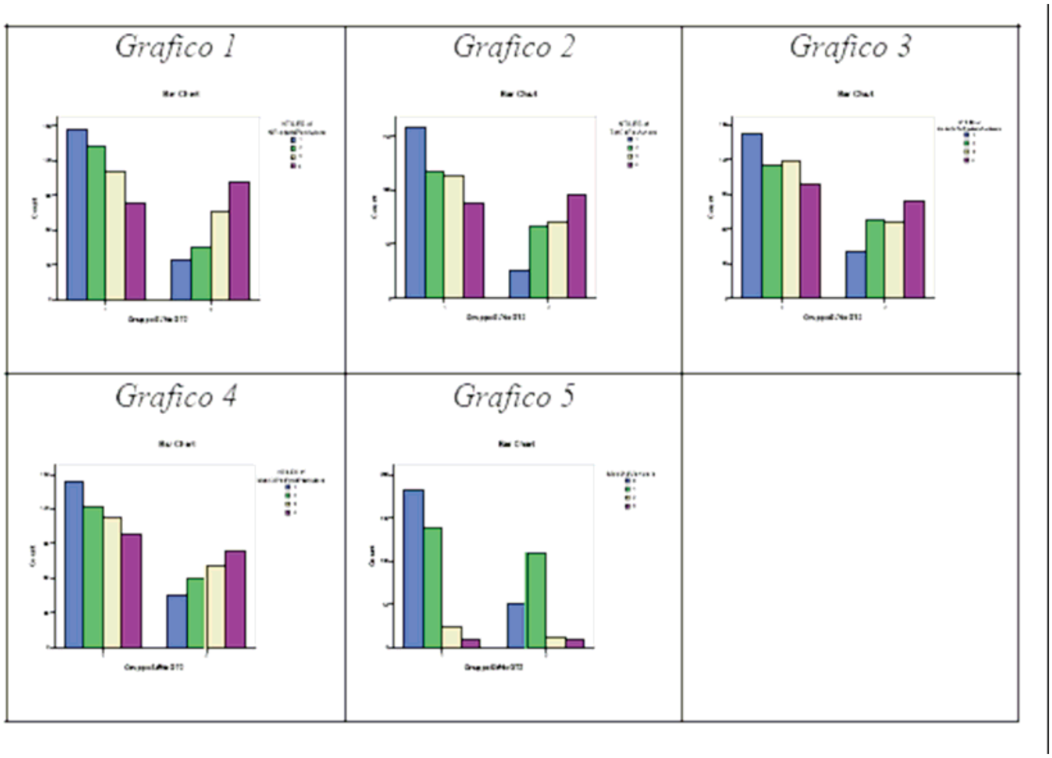


Figure 4 – Pearson Chi-Square testing

The only variable attributable to human resources that is related to attributes of network (size and centrality of the actors) in a significant way is represented by the scientific sector of research (SSD). In particular it has the following correlations measured at second level of network (at least 3 joint publications):

- Component Size [Pearson Chi-Square: 152,691; df: 60; Asymp. Sig. (2-sided): ,000];
- Degree centrality [Pearson Chi-Square: 83,563; df: 50; Asymp. Sig. (2-sided): ,002]
- Harmonic Closeness centrality [Pearson Chi-Square: 218,268; df: 160; Asymp. Sig. (2-sided): ,002].

## 5. Conclusions

The analysis has confirmed the importance of collaborations for researchers performance, hence the importance of membership within scientific networks and also the need to consider their attributes, such as dimension and centrality, to assess the quality of teaching and research activity.

Specifically, we can argue that the participation in scientific networks can improve the scientific productivity, the researcher visibility and his career advancement (upward mobility). Also the specificity of the network are related to scientific performance of university, this is showed by the greatest number of significant relations with the size and attributes of centrality (all relations are positive).

The analisys shows that the membership in distinct SSD (indicator of human capital) is tied to specific forms of collaboration in scientific networks (for size and centrality) and this is important to define the future address of knowledge sharing in this scientific field.

The correlation analysis confirms that the identified indicators for the researchers in training (Phd students, post docs students, scholars..) and international mobility are related with the size of the network, with centrality degree and the closeness of actors. In the same way, the funding for research projects derived by other sources depends by size of the network.

The analysis confirmed that 3 is the minimum number of joint publications in one year for the definition of a scientific network in Chemistry.

In conclusion, the analysis confirms that, in general, the scientific staff of universities will maximize their performance through participation in the network, but there is a trade off between research and teaching with regard to the times. It is true that the quality of teaching is higher if supported by a constant and valid research. Therefore, the implications emerging from the analysis suggest to the university management to increase the efforts to support international collaborations in all fields of science, balancing the timing of teaching with those of research, and equitably redistributing human resources between the two activities.

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