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The multidimensionality of the academic performance in the applied sciences end engineering: Evidence from a case study

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**The multidimensionality of the academic performance
in the applied sciences and engineering: evidence from a case study**

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The multidimensionality of the academic performance in the applied sciences and engineering: evidence from a case study

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Previous investigations showed that Italian university professors are the authors of a considerable share of the EPO patents owned by firms in science-based technological classes. The analysis of USPTO patents conducted in this paper confirms those results. Moreover, data collected through interviews to patenting professors show that the realization of patents in the context of researches funded by firms involves undergraduate and PhD students, university fellows and technicians: thus, the role of the academy appears significantly augmented.

The paper also brings to light the role of academic centres of excellence in the cooperation between university and industry. Focusing on the field of electronics and applying the methodology of Social Network Analysis, the importance of a centre of excellence is pointed out, not only in the production of codified knowledge, but also in the diffusion of know-how through personal relationships. It is shown that a centre of excellence, which is the core of the principal component of the network, gives rise to a real invisible college, in which the academic and the technological world are interpenetrated. And this interpenetration does not hinder purely scientific production, but rather it seems to favour it.

1. Introduction*

The charge levelled at the Italian university system of being self-referential and unable to communicate with industry is a rather trite commonplace. Some recent empirical investigations (such as those collected by Bonaccorsi, 2003) have shown the importance of taking into account its internal heterogeneity, from the point of view both of the quality of research and of the intensity of relationships with the external world. In fact a few scientific teams are at the frontier of scientific research and also active in the creation of new ideas and prototypes useful for industry, while others stagnate. Furthermore, in many fields the major obstacle to the relationships between “the Republic of Science” and “the Reign of

* This research could be realized due to the co-funding of the project by the University of Pavia and the Italian Ministry of University and Scientific Research (MIUR 2003, protocol 2003133821_006). We thank Stefano

Technology” is that no Italian firms exist possessing the competences which are required to absorb the results of scientific research.

The Italian system does not escape the general conditions which the most attentive students of technical progress and of the relationships between science and technology have clearly depicted. In particular, Nelson and Rosenberg have underlined the fact that a large part of the disciplines comprised in the academic curricula (in scientific or engineering departments) developed precisely to meet the knowledge and education requirements of firms in fields such as the production of integrated circuits, lasers, software or drugs, and that in these fields, for research to be effective, applied scientists must be “intimately familiar with technology” (Nelson and Rosenberg, 1998, p.47). This clearly implies that the collaboration between university and the firms specialised in those advanced fields is a mutual necessity.

This article has the aim of contributing to highlight the multidimensionality of university performance in the engineering and scientific disciplines of applied nature and to come up with a methodology to help single out the centres of excellence existing in a country. In particular, the attention is focused on the relationships between university and industry in Italy and on the role of university within the national system of innovation.

The evaluation of performance, not so much of entire universities but rather of the different groups of academic research – the laboratories into which scientific-technological departments are subdivided - is important not only *per se*, to gain a correct picture of the university system and of its relationships with industry, but also from a policy perspective, as a solid ground for an effective allocation of the resources assigned to research.

Our starting point are the contributions of Balconi, Breschi, Lissoni (2003, 2004) and Balconi, Borghini, Moisello (2003). BBL (2003) developed a new method to bring to light the university departments most active in technological activity, based on the examination of the *patents which are assigned to firms but protect an invention created by university professors*. By counting the number of university professors who authored patents applied by firms to EPO (European Patent Office) and comparing the number of their contributions with that of the inventors who are not professors (mostly employees of the patenting companies) they could show that not only the role of Italian university in inventive activities is not at all negligible, but in some areas (biotechnology, electronics, chemistry, pharmaceuticals) it is

Breschi and Francesco Lissoni for their useful suggestions and all the academic inventors of the University of Pavia for their willingness to answer our questions. The usual disclaimers apply.

crucial¹. These patents result from activity of research *funded by firms* and *performed by professors* on the basis of contracts between the funding firms and the university departments². Moreover BBL (2004) have shown the crucial role played by academic inventors in connecting individuals and components of the Italian social network of inventors.

As regards BBM, they realised an in-depth case study of the University of Pavia. Through the analysis of several indicators, such as the number and volume of contracts between university departments and firms, the number of patents signed by professors³, the amount of research funds at their disposal through external organizations such as research-hospitals, consortia or other public research entities (e.g. CNR, INFN etc.) and the number of publications co-authored by professors and industrial researchers, they contributed to question the appropriateness of the ivory tower metaphor, that relates to an academic sphere self-referential and separated from the demands of the real world. The picture emerging from their study of the relationships between university and industry confirms that the scientific quality of research is the most important condition to give rise to fruitful exchanges.

On the basis of the results cited above, our objective has been to deepen our knowledge of various aspects which so far remained unexplored.

Firstly, we have sought to further clarify the role played by the university system in the production of inventions appropriated by firms, by examining the participation to the research teams giving rise to patents of other members of the academic world, besides professors, such as *fellows, post-docs, last year students preparing their final dissertation, university technicians and PhD students*. This has been accomplished by interviewing the academic inventors of the University of Pavia, a prestigious university of medium size located at about

¹ In the empirical literature, patents have been used especially to test the geographical mediation of knowledge spillovers (Jaffe 1989, Jaffe *et alii* 2000) or to prove the increasing connection between science and technology, through the analysis of the citations of scientific articles made by patents (Narin *et alii*, 1992 and 1995). See also Hall, Jaffe, Trajtenberg, 2001 and Jaffe and Trajtenberg 2002. BBL's methodology is innovative with respect to these streams of investigations and it is free from the ambiguities and problems concerning the interpretation of citations as indicators of spillovers or of direct ties.

² This practice is diffused in most countries, United States included, where universities are themselves assignees of a high number of patents, but it has never been investigated. Patents assigned to universities, in general, derive from researches *funded by governments* and are especially concentrated in the field of bio-sciences (as shown by D.Hicks *et alii* 2001, Mowery *et alii* 2001, 2002). As is well known, since a few years ago also the main Italian universities created in-house patent offices, imitating the American model, but the number of patents they have applied for so far is still very limited. Only in a few years it will be possible to evaluate the costs and benefits deriving from this activity (on the American case see Colyvas *et alii*, 2002). However, this paper does not examine this aspect.

³ In particular, the analysis of patents signed by professors and assigned to firms, carried out at the level of a single university, could be realized manually instead of automatically (as was done by BBL for an analysis at the national level). This resulted in a higher level of precision.

30 km south of Milan, the professors of which in the previous investigations were particularly active in the production of patents. The evidence collected is summarized in section 1.

Second, we have examined in depth the social network of Italian inventors in order to bring to light the differential contribution in the connection of nodes given by the most distinguished university teams. The idea underpinning our empirical investigation, based upon the observations of Nelson and Rosenberg, was that in the applied sciences and in the engineering disciplines scientific and technological proficiency should be related. Thus, in the second section we focused our attention on a particular scientific-technological field – electronics – and on the role played within the sectoral network of the inventors by the Pavia school of microelectronics, which is particularly eminent in the European scientific context and internationally renowned⁴. Thanks to our collection of data through interviews and the availability of the list of the persons graduated in the University since 1975, we could precisely identify the members of the Pavia school of microelectronics and examine their position and role in the national network of inventors⁵. We also sought to unveil the role of professors in training new industrial inventors⁶, by examining to which organization were affiliated the co-authors of the first patent of industrial inventors.

Finally, it is rather obvious that if a renowned academic centre of excellence also plays a crucial role in the technological network which revolves around the creation of inventions, this means that the production of patents does not divert the activity of professors from their main institutional task, the creation of open knowledge with no restriction in use. However, to prove the validity of this argument with empirical evidence, we also compared in the last section the scientific production of academic inventors with that of a control sample formed by not patenting professors not patenting, resorting to the database *Web of Sciences* of the Institute of Scientific Information (ISI).

⁴ We recall that STMicroelectronics opened a laboratory inside the university campus and that 4 other multinational firms recently set up design centres in the area in order to hire the young designers who graduated locally and to collaborate and keep contacts with professors. Moreover, from the analysis of the articles published in the period 1999-2001 on the most important international journal of the field (*Solid State Circuits*), we also found that the universities of Pavia and Leuven (Belgium) were the only European ones which contributed significantly.

⁵ In Italy professors are officially subdivided into disciplinary sectors (used to carry out national competitions for the assignment of tenures). We could therefore compare the professors belonging to the sector of electronics, which in the year 2000 was named K01X and later ING-INF/01.

⁶ As put by Pavitt (1998, p.796), “trained scientists and engineers are considered by many business practitioners as the primary benefits of academic research”.

2. The production of patents by university professors and their collaborators: the case of the University of Pavia

To further develop the analysis of the collaborations between university and industry revealed by the examination of patents authored by professors and assigned to firms (BBL 2003, 2004), we studied the case of the University of Pavia. The patents are mainly yielded in the context of researches funded by firms and performed within university departments and are part of the output of these researches, which comprises publications, realization of prototypes and training of graduate and undergraduate students working for their final dissertation.

We started by realizing two steps: i) since previous contributions only considered the patent applications to the European Patent Office (EPO), to complete the picture we also examined the USPTO database (United States Patents and Trademarks Office) ii) we interviewed the professors authoring USPTO patents, asking them to identify their co-inventors and to point out whether they were internal or external to the academic world.

2.1. The patenting activity of the professors of the University of Pavia

According to our findings, 31 professors of technical and scientific disciplines with a tenure in 2000/2002 at the University of Pavia (full and associate professors and so-called researchers) signed 139 USPTO patents (to which 11 applications must be added) granted in the period 1978-2002. These patents are mostly assigned to private firms ⁷. Table 1 shows the list of the patents' assignees and of the departments where the researches (giving rise to the patents) were performed. The production of patents is concentrated in the departments of Electronics with 105 patents and of Pharmaceutical Chemistry with 23 patents. Among the assignees, STMicroelectronics is particularly important.

Also the productivity of professors has a very skewed distribution (table 2): 5 professors, belonging to the above mentioned departments, are the authors of 77% of the collaborations (signatures) to the creation of patents, while 19 professors, amounting to 61,3% of the total, contributed to only one patent. Thus it is only in the fields of electronics and pharmaceutical chemistry that the production of patents is a stable activity of some professors.

⁷ More precisely, we recall that a questionnaire submitted to professors reveals that 20 patents were produced before their academic appointment (namely when some future professors were still employees of corporations).

Table 1 – List of the assignees of USPTO patents which comprise among the authors professors of the University of Pavia

<i>Assignees</i>	<i>N° patents</i>	<i>%²</i>
STMicroelectronics S.r.l.	79 (+ 12) ¹	63,2
Marelli Autronica S.p.A.	5	4,0
Atmel Corporation	2	1,6
Italtel S.p.A.	2	1,6
Cselt S.p.A.	1	0,8
Pirelli Cavi S.p.A.	1	0,8
Quanta System S.r.l.	1	0,8
Siemens S.p.A.	1	0,8
(C.I.S.AND. S.p.A.)	(1)	
<i>Total patents signed by professors of the Department of Electronics</i>	<i>92 (+ 13)</i>	<i>73,6</i>
Jagotec AG	12	9,6
Lisapharma S.p.A.	3	2,4
Ekita Investments N.V.	2	1,6
APR Applied Pharma Research SA	1	0,8
Eurand International S.p.A.	1	0,8
Jagotec AG ; Synthelabo	1	0,8
Laboratorio Farmaceutico C.T. S.r.l.	1	0,8
Pharmidea S.r.l	1	0,8
Sigma-Tau S.p.A.	1	0,8
<i>Total patents signed by professors of the Dep. of Pharmaceutical Chemistry</i>	<i>23</i>	<i>18,4</i>
The Regents of the University of California	(5)	
Johnson & Johnson	1	0,8
(Montedison S.p.A.)	(5)	
Medtronic Inc.	1	0,8
Policlinico San Matteo; Ist. Naz. per lo Studio and the Cura dei Tumori	1	0,8
(Dataprocess S.p.A.; Italora S.p.A.)	(1)	
(Enichem Sintesi S.p.A.)	(1)	
Amersham Pharmacia Biotech UK Limited	1	0,8
<i>Total patents signed by professors of other departments of life sciences</i>	<i>9 (+7)</i>	<i>3,2</i>
Società Italian Vetro - SIV - S.p.A.	2	1,6
<i>Total patents signed by professors of the Dep. of Nuclear Physics</i>	<i>2</i>	<i>1,6</i>
<i>Individual patents (professors of Nuclear Physics and of life sciences)</i>	<i>4</i>	<i>3,2</i>
<i>Total patents</i>	<i>125 (+ 25)</i>	<i>100,0%</i>

Note: ¹ Within brackets: the patents realised when the professor authoring them had not yet a tenure at the University of Pavia or in the context of researches performed at other universities. ²The percentages are calculated with the exclusion of the patents within brackets. ³In the group of life sciences the following departments are included: Biochemistry, Organic Chemistry, Internal Medicine, Experimental Medicine, Paediatric Sciences, Ematologic and Pneumologic Sciences, Physical Chemistry, General Chemistry. We pointed out separately the Department of Pharmaceutical Chemistry, given its significance in patenting activity.

Table 2 – Distribution of professors on the basis of the number of patents signed

<i>N° signatures</i>	<i>N° professors</i>	<i>% on the total of patenting professors</i>	<i>Total signatures</i>	<i>% on the total of signatures</i>
1	19	61,3%	19	11%
2	4	12,9%	8	4%
3	1	3,2%	3	2%
5	2	6,5%	10	6%
12	1	3,2%	12	7%
14	1	3,2%	14	8%
22	1	3,2%	22	12%
36	1	3,2%	36	20%
55	1	3,2%	55	31%
<i>179</i>	<i>31</i>	<i>100,0%</i>	<i>179</i>	<i>100%</i>

At this point it is possible to compare the number of patents applied for at EPO⁸ with the number of applications at USPTO, authored by the same Pavia professors. It has to be noted that the coverage by the EPO database of the patents applied since the second half of 2001 is incomplete, since the European system provides for a period of secrecy of 18 months from the date of filing⁹. After this deadline, the patent application can be published and the patent protection starts.

As shown in table 3, the dimension of the phenomenon is substantially identical in the two cases.

Table 3 – Comparison of the number of patents filed at EPO vs. USPTO which include among the authors Pavia professors with a tenure in the period 2000/2002

<i>EPO dec.1978 - dec.2002</i>	<i>USPTO dec.1978 - mar.2003</i>
Total N. of professors: 31	Total N. of professors: 31
Total N. of patents: 126	Total N. of patents: 150 ¹
<i>Total N. of signatures²: 155</i>	<i>Total N. of signatures: 179¹</i>

Note: ¹ Of which 10 (on 150) are patent applications, with 11 signatures (on 179) of professors.

² Since the same patent may include among the authors more than one professors, the number of patents signed by professors and the number of signatures differs.

It remains to be understood what patents belonging to the two sets are the same, extended in both continents. We had then to analyse in each of the 276 patents (126 EPO and 150 USPTO ones) the code of the document to which the priority date is assigned. When two

⁸ We used the EPO database updated up to December 2002.

⁹ The date from which the period of 18 months elapses is the priority date, or when the latter is lacking, the date of filing.

patents refer to the same date and to the same document they are for certain the same patent¹⁰.

Figure 1 illustrates the results of our investigation.

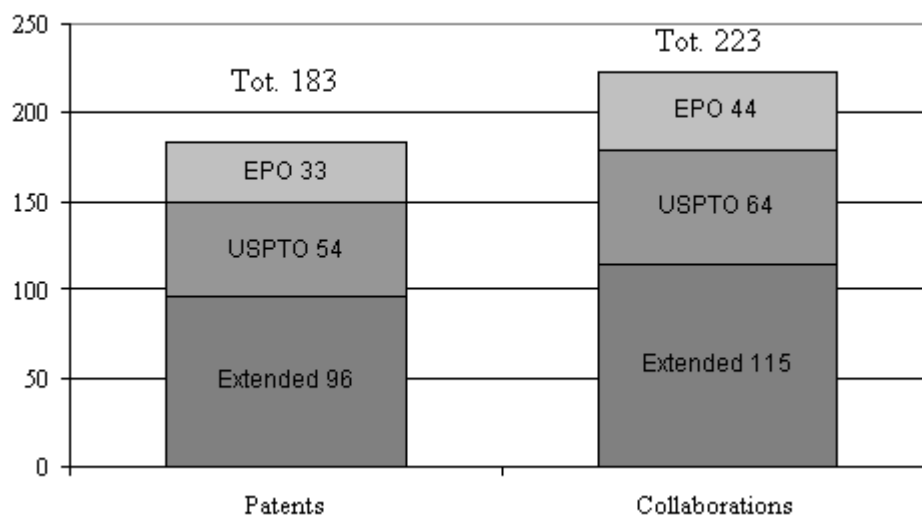


Figure 1 – Number of patents authored by at least one professor of the University of Pavia and number of collaborations (signatures) to patents (1978-2002)

The large majority of patents is extended in both continents. However 36% of the USPTO patents and 26% of the EPO ones have no equivalent. Comprising also "only EPO" patents, the number of Pavia professors who authored patents increases to 38, the number of collaborations (signatures) to patents to 223 and of patents authored by at least one Pavia professor to 183. The relation with industry emerging from these data is more important than the previous analysis based on EPO patents showed.

Table 4 presents the distribution by department of these 183 patents. Compared to the distribution of USPTO patents, the role of the Department of Pharmaceutical Chemistry and of the other departments in the field of life sciences is increased.

¹⁰ This method of verifying the equivalences was suggested by Franco Zorzoli (Italian and European Patent Attorney), since the official equivalences stated by EPO are not useful to our aims, being too generic.

Table 4 – Subdivision by department of the different categories of patents authored by Pavia professors (1978-2002)

<i>Department</i>	<i>Extended patents</i>	<i>USPTO Patents</i>	<i>EPO Patents</i>	<i>Tot. patents</i>	<i>Shares of the departments</i>
Pharmaceutical Chemistry	18	5	14	37	23,9%
Other life sciences	4 (+ 3)	2 (+ 4)	9 (+ 3)	15 (+ 10)	9,7%
Electronics	66 (+ 2)	26 (+ 11)	6	98 (+ 13)	63,3%
Nuclear Physics	3	1	1	5	3,2%
<i>Total patents</i>	<i>91 (+ 5)</i>	<i>34 (+ 15)</i>	<i>30 (+ 3)</i>	<i>155 (+ 23)</i>	<i>100%</i>

Note: In brackets the patents realized from Pavia professors before getting a tenure.

In general "only USPTO" patents are either the oldest ones, realised when the EPO was just born and firms in Europe applied for patents directly in the various countries, or in the latest ones (as USPTO data are more updated). "Only EPO" patents are instead mainly patents owned by European firms who decide to extend them in the United States only if they consider it worthy from a commercial or strategic perspective (but also the opposite may take place, when the assignees are American, as in the case of the University of California)¹¹.

Figure 2 shows the evolution over time of the number of patents authored by Pavia university professors, in the United States and in Europe. It must be considered that the production of patents during the Eighties is understated, since the data do not refer to *all* Pavia professors with a tenure at that time, but only to the production of patents at that time by professors with a tenure in the period 2000/2002, as already explained.

The decrease in the most recent years could be due, beyond the delay in updating the data, to the unintended consequences of a bad law. In fact up to October 2001, the Italian patent law (decree 29/06/1939, n°127) treated private companies and public administration in the same way, thereby allowing the firms funding university research to own the patents authored by professors. The new law 383 of October 2001, art. 24 bis, known as "Tremonti bis", changed the situation¹², attributing to university or state employees "the exclusive

¹¹ As to professors, 7 realised "only EPO" patents and as many "only USPTO" ones. They are of professors with a marginal patenting activity (with only one contribution), with the exception of one case (with 5 contributions).

¹² For a discussion of the new law from the juridical view point, see V. Di Cataldo, 2002, according to whom (p.341) the new Italian law "seems to derive from provincialism, scant awareness of the positions commonly held in the world and of their reasons."

ownership of the rights deriving from the patentable invention of which they are authors...”.

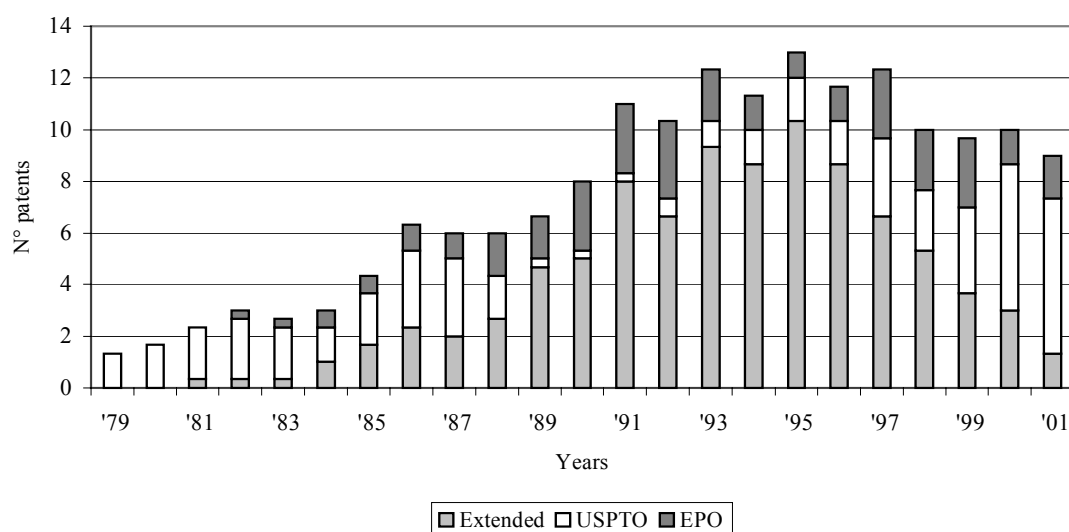


Figure 2 – Evolution over time of the number of patents signed by professors (three years mobile means)

This norm thus forbade those firms which funded university researches to apply for patents authored by professors. Clearly, the politicians passing the law ignored that university professors in general have neither the resources, nor the organizational capacities nor the interest to become themselves the assignees of the patents deriving from the researches funded by firms, but instead they are eager to obtain research funds (that permit *in primis* to pay young researchers), to collaborate with industrial researchers and to access firms' technologies, since all these factors significantly augment their productivity and success. Thus, a well functioning mode of collaboration between university and industry has been jeopardised by a law based upon an ideological orientation and ignoring reality. After a period during which firms reduced their funding, the problem has been “solved” through more bureaucratic work of university offices, in order to find the *escamotages* required to sidestep the law and to convince firms that they did not face any legal risk continuing to implement the old practices.

2.2. The collaborators of Pavia academic inventors

To improve our knowledge of the cooperation between university staff and firms in patenting, we investigated the affiliation of the co-authors of academic inventors in the realization of patents, since patents authored by professors are mostly realised by teams of 3 or 4 persons. More precisely, figure 3 shows the total number of co-inventors in each patent. Note that patents authored by a single individual are only 6, while they are mainly realized by

teams of 2 to 4 co-inventors.

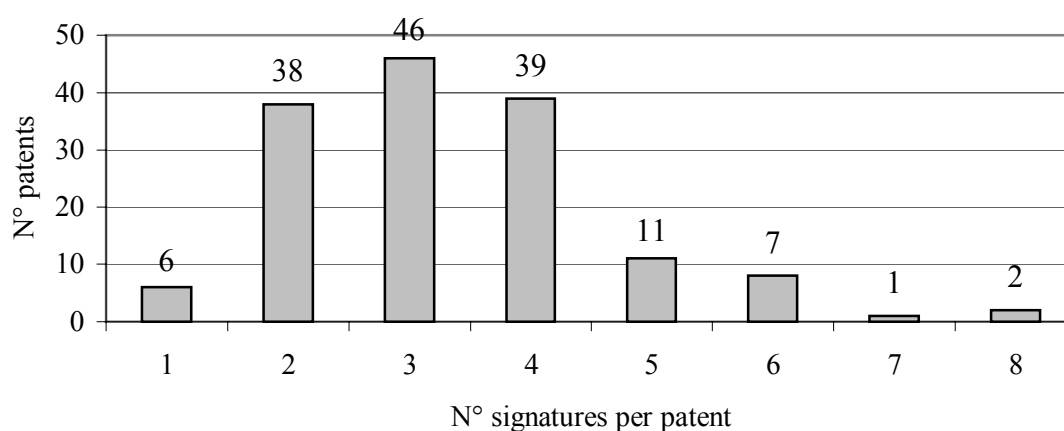


Figure 3 - Number of co-authors per each patent signed by at least one Pavia professor

In order to verify the full contribution of university personnel to the inventive activities of firms, we analysed the affiliation of the collaborators of professors. Through a questionnaire submitted to the latter we collected information on the individuals co-authoring their 125 USPTO patents. A rate of reply of 96,8% (*sic!*) permitted us to reconstruct a very precise picture, getting information on over 100 collaborators¹³. Table 5 shows the various categories of collaborators: last year students working for their dissertation, fellows, PhD students, university technicians, employees of the firms to which the patent were assigned and of other firms. Moreover, we also controlled whether firm employees co-patenting had graduated in Pavia.

¹³ The 4 patents for which we did not get information involve only 7 co-authors and 7 signatures, as against over 400 signatures analysed.

Table 5 - The co-authors of the 121 patents examined: affiliation and role in patenting

	<i>Total N° of Co-authors</i>	<i>%</i>	<i>N° of co-authors graduated at UniPv</i>	<i>N° of signatures on patents</i>	<i>%</i>
Professors UniPv	21	18%	16	159	38%
Other personnel UniPv	26	22%		69	16%
Last year students	6	5%	-	7	2%
PhD students	8	7%	5	40	10%
Fellows, post-docs	9	8%	9	18	4%
Technicians	3	3%	3	4	1%
<i>Total personnel UniPv</i>	<i>47</i>	<i>39%</i>	<i>33</i>	<i>228</i>	<i>54%</i>
<i>Professors of other universities</i>	<i>4</i>	<i>3%</i>	<i>2</i>	<i>17</i>	<i>4%</i>
<i>Total university personnel</i>	<i>51</i>	<i>43%</i>		<i>245</i>	<i>58%</i>
<i>Employees of assignee firms</i>	<i>58</i>	<i>49%</i>	<i>22</i>	<i>160</i>	<i>38%</i>
<i>Employees of other firms</i>	<i>10</i>	<i>8%</i>	<i>7</i>	<i>16</i>	<i>4%</i>
<i>Total firm' employees</i>	<i>68</i>	<i>57%</i>	<i>29</i>	<i>176</i>	<i>42%</i>
<i>TOTAL</i>	<i>119</i>	<i>100%</i>		<i>421</i>	<i>100%</i>

The results obtained are of great interest: the contribution of university to the inventive activity of firms appears significantly increased. In fact undergraduate and PhD students, fellows and technicians co-authoring patents are so numerous as professors (26 as against 25, 4 of which affiliated to other universities). As to firm employees, their number is somewhat larger than that of university personnel (68 as against 51) and 43% of them were graduated at Pavia. Moreover, 10 firm co-authors (7 of whom graduated at Pavia) belong to other firms, which are not the assignees of patents. Overall, it appears that Pavia professors were part of a quite large network; that the relationships with firm employees originated to a large extent when the latter were undergraduate or graduate students or post-docs; and finally, that the social relationships arisen during university education are an important vehicle for the connection of researchers of different firms.

A final aspect to consider is the number of contributions realised by the different actors. The fact that Pavia professors are particularly productive with regard to the patents considered, does not mean that they are so in absolute, since we do not know the number of patents realised by firm employees without the contribution of university professors. However, the fact that professors participate to various research teams involving a number of co-inventors suggests that they have an important role in connecting the research system. The following section, which focuses on the field of electronics, has the purpose to go into these aspects.

In conclusion, patenting professors exercise a clear role of *connectors of relationships*

between university and industry. The depiction of the Italian university as an ivory tower, already criticised by previous studies (Balconi, Breschi, Lissoni 2003 and Balconi, Borghini, Moisello 2003), is further invalidated by the present analysis. In fact, on the one hand it is confirmed and enhanced the direct role of university personnel in contributing to firms technological activity, through the involvement, as was shown, of graduate and undergraduate students, post-docs and technicians to the creation of inventions; on the other hand, light is shed on the importance of the indirect contribution to this activity offered by university professors through the education of the human capital required by firms to carry it out and through the texture of the networks that are considered fundamental to permit firms to absorb the novelties at the frontier of technological progress (Ziman 1994).

3. Spotting the social fallout of a scientific-technological school of excellence through the application of Social Network Analysis

In the preceding section we saw that the Department of Electronics is the most prolific of the University of Pavia with regard to the production of patents.

At this point we want verify *the position and the role* of the Pavia school of Electronics within the *epistemic community specialized in this field*. To this end, we apply the conceptual and methodological tool of Social Network Analysis (SNA) to the social relationships which emerge considering the teams co-authoring patents to which participated at least an Italian professor of electronics. As already demonstrated by Balconi, Breschi, Lissoni (2002), patents offer extremely useful information in order to measure *the social distance* and the location of the various actors in the networks of inventors.

3.1. Methodological notes

In the field of Social Network Analysis spotting the participants to a network is a complex question (Scott 1997), which is generally faced resorting to two different types of approach: the “*positional*” and the “*reputational*” one.

Put very shortly, in the *positional approach* those who occupy particular positions or belong to formally defined groups are considered members (nodes) of the network, whereas according to the *reputational approach*, the persons included are those comprised in a list of names prepared with the help of key witnesses. A variant of this second approach consists of the so called *snowballing* technique. In this case one starts by spotting a small number of individuals who are asked to indicate the participants of the network whom they know; the

same question is then repeated to the latter, and again to the individuals identified through the new answers obtained. Continuing with this procedure, the network grows by successive aggregations like a snowball.

Here both approaches have been applied. First we selected as a *starting set of actors* the Italian professors with a tenure in the year 2000 belonging to the scientific sector of electronics, who authored both USPTO and EPO patents (positional approach). Then we proceeded with the snowballing, to identify the direct and indirect acquaintances (obviously concerning the patenting activity and the related research) of these professors (reputational approach). However, the reconstruction of the social network is not based upon the answers to the question “with whom do you have ties?” made to the starting group and then to the actors of the successive circles, but singles out the personal acquaintances through the analysis of the events to which the actors participate. The “events” are the co-authored patents. In technical terms, we construct a *two-mode affiliation network*, that we project on the patent authors thereby coming up with a one-mode network.

More precisely: i) we selected all the co-authors of patents signed by professors, namely the latter's direct acquaintances (first circle); ii) we extracted from the USPTO database all patents realised by co-authors (direct collaborators), thereby drawing out the set of collaborators of collaborators of academic inventors (second circle). Since the literature on SNA (see Wasserman and Faust, 1994) demonstrates that interpersonal ties beyond the second step are no longer meaningful (A communicates with B who communicates with C who communicates with D who..., where by second step we mean the indirect tie between A and C) we decided to stop at the second circle of acquaintances.

The following figure illustrates the core of the methodology used. Let us consider, as in the figure 4A (which represents the two-mode affiliation network), a certain professor A (at the top) who signed 4 patents (from B1 to B4). He is connected directly to the co-authors (from C1 to C5) of these patents (first circle of direct ties). If actors C1-C5 co-author other patents to which actor A does not participate, as in the case of patents B5-B10, they belong to other research teams, where A is absent. We thus spot the collaborators of collaborators of A (CC1-CC11, who co-author some patent from B5 to B10), namely A's indirect acquaintances (the actors of the second circle).

The one-mode projection of the network is shown in figure 4B, where the events are "skipped" and only the ties among the inventors are drawn, both direct and indirect ones. The paths which link, directly and indirectly, the inventors to professor A are pointed out with thicker lines.

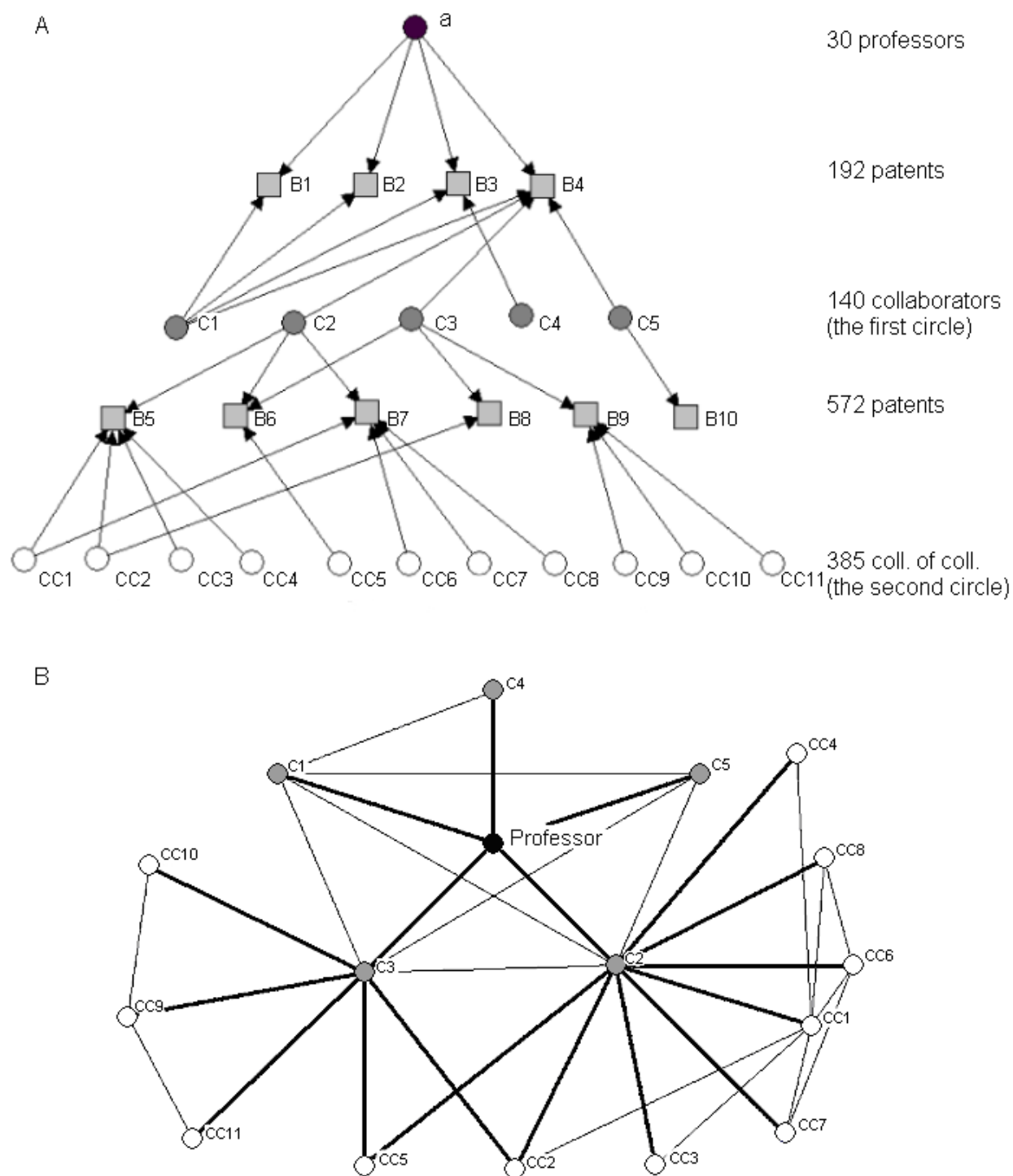


Figure 4

3.2 The size and the composition of the network

Before discussing the structural characteristics of the network of inventors (calculated with the software UCINET), the data that will be analysed are presented in detail.

Starting group (positional approach)

Our starting set of actors is the group of Italian academic inventors of the sector of electronics who authored USPTO patents: they are 30 and 5 of them belong to the University of Pavia (Unipv). Figure 5 illustrates the patenting activity of these professors, which comprises 218 contributions (signatures) to 192 patents¹⁴. Among the 5 Unipv professors (represented in black) we find 2 stars, authors respectively of 36 and 55 patents.

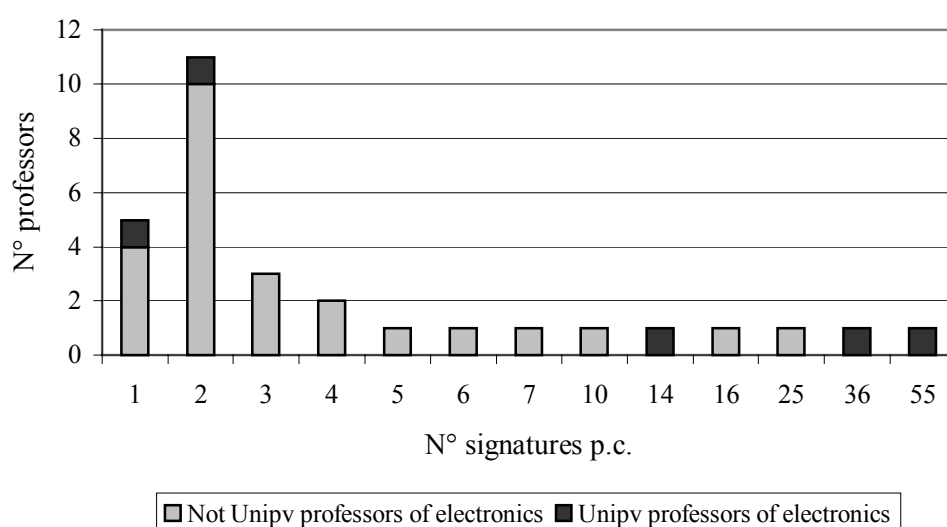


Figure 5 - Production of patents by Italian professors of electronics

First circle (reputational approach)

The direct collaborators of the 30 professors of electronics are 140 inventors “of the first circle”; they realized 1.058 contributions to 764 patents, 192 of which co-authored by professors. While we do not know if they are in some way insiders in some university (as fellows, students etc.) or rather firm employees, we could check if they graduated in Electronic Engineering at the University of Pavia¹⁵.

Table 6 shows the productivity of the various categories of actors¹⁶ comprised within the first circle, taking into account whether they graduated at Pavia or not. Interestingly, not

¹⁴ In this analysis we call generically patents both patents granted and patent applications registered at the USPTO.

¹⁵ This could be accomplished by consulting the database of COR (University Orientation Centre), which collects the data of local graduates since 1975.

only Pavia professors are the most productive category (especially due to the presence of the stars), but also Pavia graduates are more productive than average.

Table 6 - Mean per-capita productivity of the various categories of inventors comprised within the first circle (170 inventors)

<i>Categories of inventors</i>	<i>Mean n° of patents p.c.</i>	<i>Q₁*</i>	<i>Q₂*</i>	<i>Q₃*</i>	<i>Q₄*</i>
30 professors + 140 inventors of the first circle	7,5	1	3	10	60
Professors UniPv (5)	21,6	-	-	-	-
All professors (30)	7,3	2	2,5	5,8	55
Not professors (140)	7,6	1	3	11	60
not graduated at Pavia (101)	6,9	1	3	9	60
graduated at Pavia (39)	9,4	1	5	12,5	45
Pavia school comprised in the first circle(47)**	10,9	1	6	14	55

Note: * Q₁, Q₂, Q₃, Q₄ are the value (N° of patents per-capita) under which are located respectively 25%, 50%, 75% and 100% of inventors.

**The *Pavia school* comprises the following categories of inventors: UniPv professors (5) + professors of other universities but who graduated at UniPv (3)+ not professors who graduated at UniPv (39).

Table 7 shows the category to which the most prolific inventors (among the 170 ones) belong. One notes that only 2 out of 10 are professors, the two Pavia stars, one of whom is not graduated at Pavia. This is consistent with the well known fact that excellence schools are not formed through a local recruiting of professors, but seeking to attract the best researchers available "on the market". In our case, the recruited star was a researcher at Berkeley internationally renowned, graduated in another Italian university, who after transferring to Pavia university gave a substantial contribution to the construction of a distinguished school with regard both to the education imparted and the research performed.

Moreover, the table shows that also half of the most prolific not academic inventors were graduated at Pavia¹⁷. Overall, 6 inventors out of the first 10 are of Pavia school. Evidently this suggests that the quality of their education has been particularly high.

Thanks to our interviews, we could also verify that the inventor ranking third is a UniPv doctor of research recruited by a firm, those ranking 4th and 9th after graduation continued to cooperate with Pavia professors and, finally, that the one ranking 6th cooperated with a Bologna professor who realised a high number of patents. Thus, the collaboration *post-lauream* with university centres of excellence appears to be productive for firm researchers.

¹⁶ Remember that we know the entire production of patents by the inventors of the first circle.

¹⁷ Pavia school comprises 78 inventors: 5 UniPv professors, 3 professors of other universities but who graduated at UniPv and 70 UniPv graduates who are not professors.

Table 7 – The first 10 inventors in terms of the number of patents authored

<i>Ranking</i>	<i>Professor</i>	<i>Graduated at Pavia</i>	<i>N. of signatures</i>
1	NO	NO	60
2	YES*	YES	55
3	NO	YES	45
4	NO	YES	42
5	YES*	NO	36
6	NO	YES	35
6	NO	NO	35
8	NO	NO	34
9	NO	YES	28
9	NO	NO	28

Note: *Professor of the University of Pavia.

Second circle (reputational approach and snowballing technique)

From the analysis of the 572 patents (events) co-authored by the direct collaborators of professors, we obtained all the acquaintances at distance 2 from academic inventors of the electronic sector. They are 385 inventors of the second circle (all the patents of whom we do *not* know, while we only know that they realized 1.006 collaborations with the inventors of first circle).

Complete network

Overall, the 764 patents analysed have 2.282 signatures by a set of 555 inventors. 30 of these, as we already know, are the professors from whom we started and 140 are their direct collaborators forming the first circle: a sub-set of 170 inventors of whom we know all patents and all direct ties. The relationships generated by the 764 patents are 3.046.

Overall the “Pavia school” comprises 78 inventors: i) 5 Pavia professors from the starting group ; ii) 42 Pavia graduates belonging to the first circle, 3 of whom are professors in other universities and 39 are not professors; iii) 31 not academic inventors graduated at Pavia, belonging to the second circle.

In the complete network the 78 inventors of the Pavia school represent 14% of the total. Given the high level of productivity, the role performed by these inventors within the social network is higher than their numeric weight. In fact, in terms of number of collaborations to patents, the contribution of the Pavia school increases to 30% (683 signatures out of 2.282). Moreover, if we consider each patent with a Pavia graduate or professor among the authors, the contribution raises to 49,7%, including 380 out of 764 patents analysed.

3.3 The analysis of the components of the social network of inventors

In order to describe the structure of a network (namely of a graph), it is fundamental first to identify the number and the size of its components.

To define a component, the concept of connection has to be introduced. A graph is connected when all its nodes are connected to one another through some path. A component of a graph is a maximal connected subgraph: that is, each node of a connected subgraph can “reach” all other nodes through one or more paths, but it has no connections with nodes not in the subgraph.

Thus all members of a component can communicate to each and every other member either directly or through chains of intermediaries. Obviously, isolated nodes do not have these opportunities. Therefore the model of the components of a graph, their number and size, offer a crucial indication of the opportunities and obstacles to communication.

The software UCINET identified 10 components in our network of 555 inventors: a very large one and 9 much smaller ones. Remember that, by construction, any component must contain at least one professor. Moreover, we do not know whether the collaborators of the professors are insiders of the academic world (as students, fellows etc.), but we assume that insiders are among the direct collaborators of the professors. Therefore, the more extended are indirect ties, the more important, in our view, is the role of professors in connecting the academy with industry. That said, what is of particular interest is: i) the concentration of professors in the principal component; ii) the differential position of the members of the school of excellence, and particularly of the professors of the latter, with respect to the other professors included in the network.

Principal component: with 18 professors, connectors of the academic and the industrial world

The complexity of the overall network can be appreciated by observing the subgraph corresponding to the component of larger size (component 1, figure 6). The latter includes 479 individuals, 18 of whom are professors: 4 of these belong to the University of Pavia and 3 to other universities, but graduated at Pavia. Overall, the inventors of Pavia school (graduates and professors) in this component are 73 and represent 15,2% of the actors.

Notice that the inventors “reachable” through a path of length ≤ 2 from Pavia professors, through direct collaborators (66) or indirect contacts (212 collaborators of collaborators), are 278.

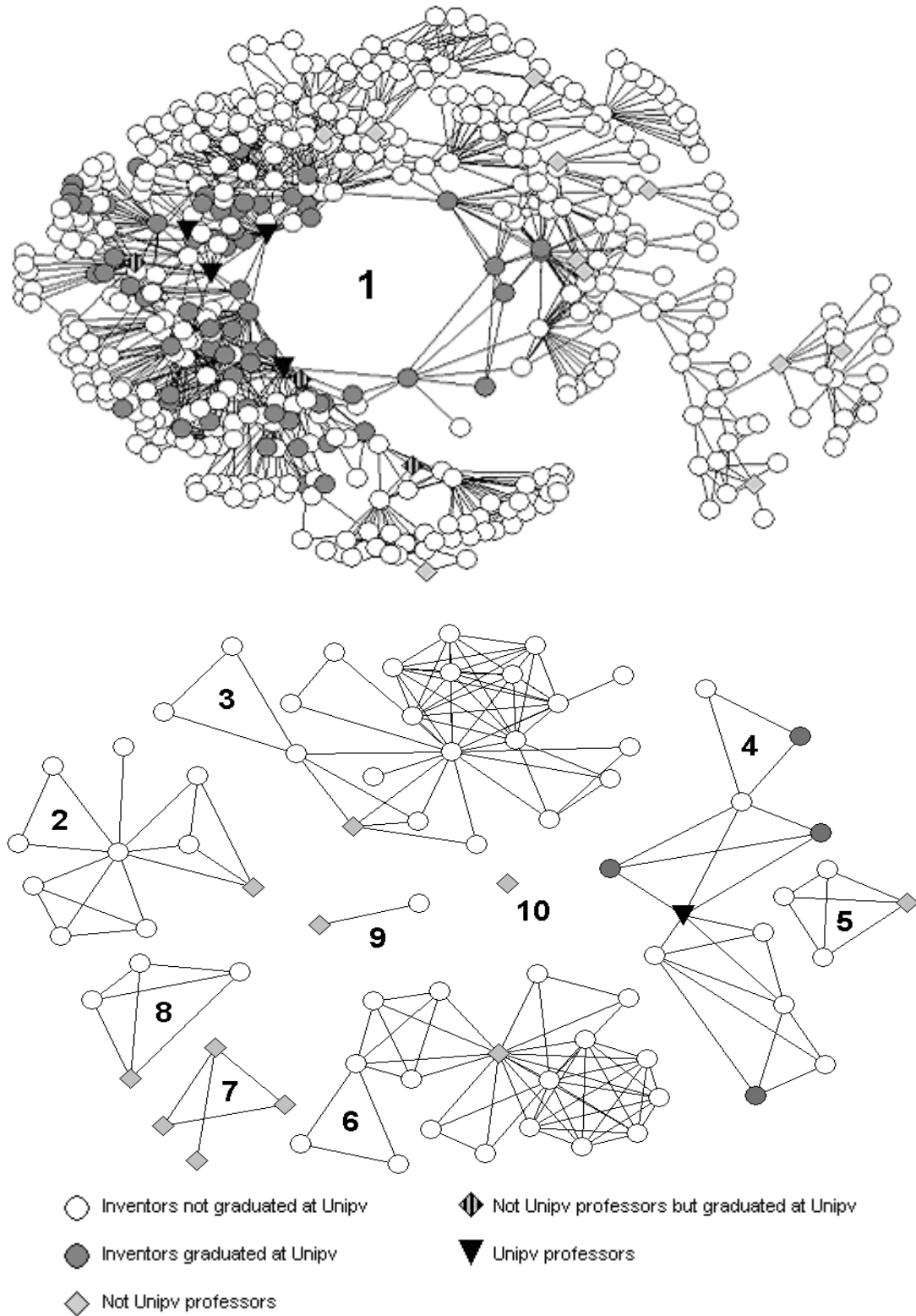


Figure 6

Medium size and small components: with 4 professors connected to the external world

- *Component 3* (22 nodes): one professor, 4 inventors connected directly and 17 collaborators of collaborators.

- *Component 6* (18 nodes): in this case the inventors who directly collaborate with the professor are 15, while only 2 are connected indirectly. Patenting activity is strictly connected to the professor, with few external ties.
- *Component 2*: Subgraph with 10 nodes, 3 of whom are direct collaborators of the professor included and 6 collaborators of collaborators.
- *Component 4*: with 11 inventors, this is the only component, besides the principal one, which contains one Pavia professor (recognizable by the triangle) and 4 Pavia graduates (represented by dark grey circles), 2 of whom are indirectly connected to the professor.

Very small components and isolates: ivory towers, with 8 professors

- *Component 5 and 8*: they are identical, being made by one single professor and 3 direct collaborators, who patent only with the professor.
- *Component 7*: made by 4 professors (not all directly connected) and no other collaborator.
- *Component 9*: it comprises only one professor (the diamond) and his collaborator.
- *Component 10*: a single isolated professor, without collaborators.

In conclusion, the majority of professors participate in the largest component and an even larger number can be considered connected with industry. In particular, the Pavia school is at the centre of wide network, rich of opportunities for the exchange of knowledge. Almost all of its members are located in the principal component, the one which offers more occasions of learning, diffusing know-how and getting new acquaintances.

So far the analysis of the network has shown the existence of relationships, but not their intensity. This property can be represented graphically through a *valued graph*, where the thickness of the lines that link the nodes depends on the number of collaborations which have taken place among the actors. In our specific case the tie between two nodes is valued on the basis of the number of times two inventors are co-authors of patents. In particular, figure 3 shows only the collaborations repeated at least 4 times.

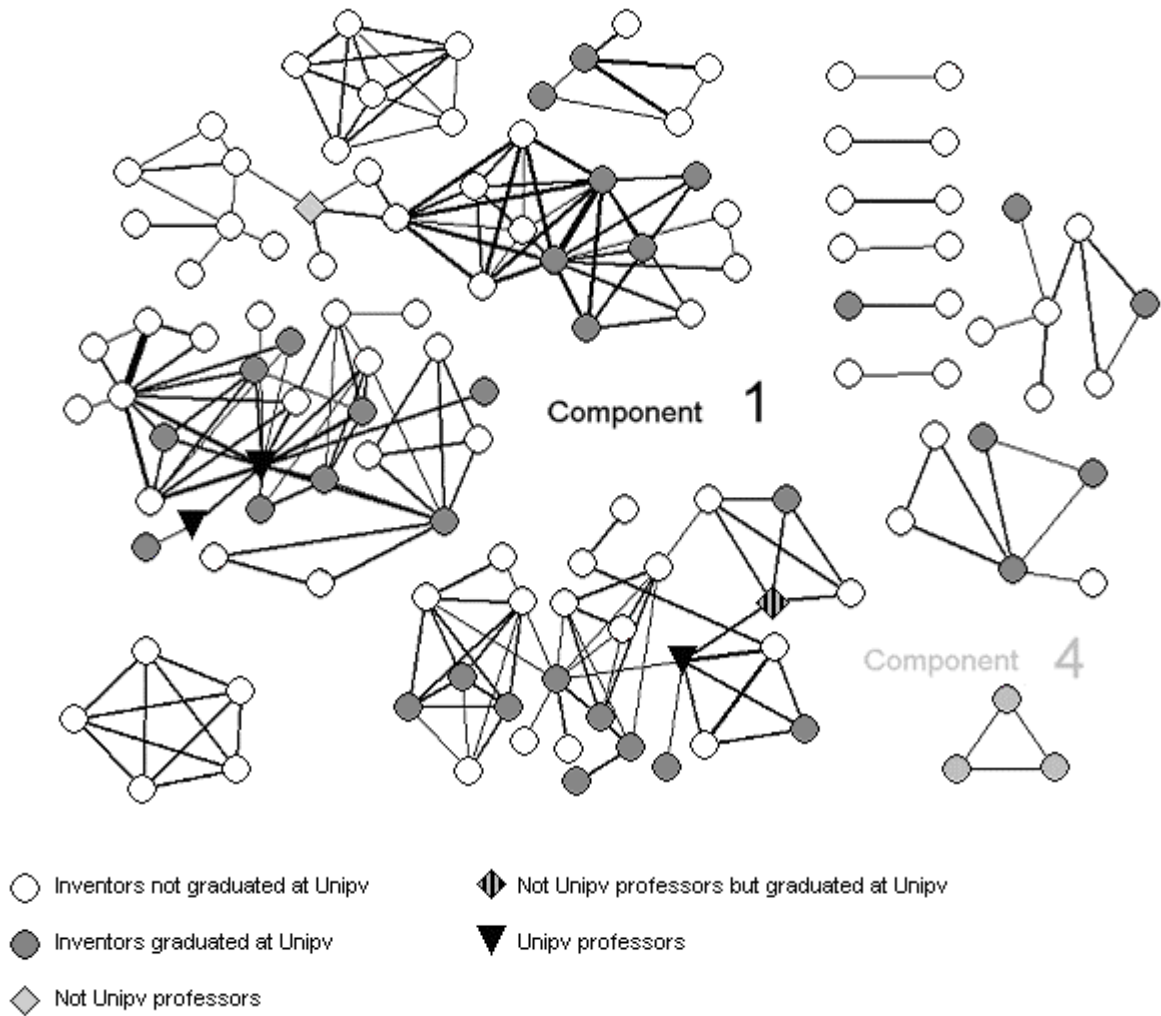


Figure 7

The new picture comprises 121 inventors, 36 of whom (30%) belong to the Pavia school: 32 not professors graduated at Pavia (dark grey circles), 3 Pavia professors (black triangles) and one of another university, but graduated at Pavia (black diamond). Overall 15 components emerge deriving from the previous ones, 14 of which originate from the split of the principal component and one from component 4 (3 inventors represented with clear grey circles).

Once more one notes the major role of Pavia school inventors, due to the fact that the patenting activity which they perform is not occasional and hence creates strong and persistent ties with collaborators.

With regard to this, we calculated the duration of the 199 relationships repeated at least 4 times between the 121 inventors. The mean duration is of 4,17 years and the median is of 3 years; the distribution by years of the relationships is depicted in figure 8.

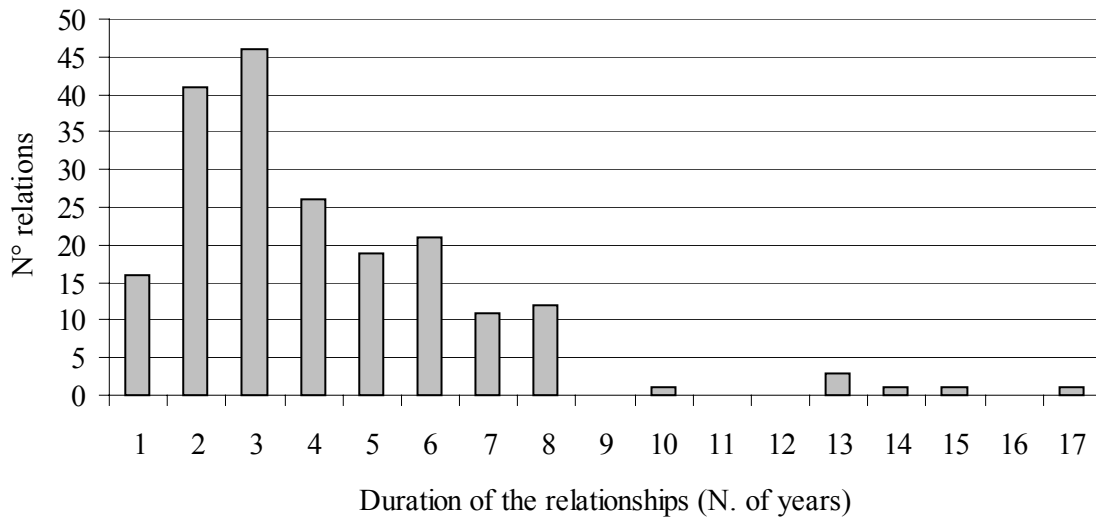


Figure 8

3.4 The centrality of academic inventors in the social network

The concept of centrality of individuals within their social networks is of crucial importance and has been one of the first to be developed and operationalised from SNA students (Bavelas, 1950).

The most simple way to measure the centrality of a social actor (namely of a node in a graph) is to count his degrees. The degree is the number of nodes to which a node is adjacent¹⁸. Thus, a social actor who has a high degree compared to the others is central in the sense that he is “well connected” and finds himself “at the heart of the situation”.

In our case an individual with a (relatively) high value of *degree centrality* is one who collaborates and has direct relationships with a number of inventors, with an immediate exchange of scientific or technical knowledge. An individual of this type performs an important role in the epistemic community to which he belongs, since he transmits and diffuses uncodified knowledge to many persons, circulating know-how and information between the various research teams in which he is involved.

Obviously the values of the degree centrality of the various actors are correlated to the level of their productivity. What positively affects the *degree centrality*, in addition to productivity, is the number of co-authors per patent and the variety of research teams to which the inventor participates.

¹⁸ Centrality so defined is based on the number of lines which are incident to a given node compared to the other ones.

Table 8 enumerates the highest 10 values of degree centrality reached by the 170 inventors comprised in first circle, of whom we know all the collaborations. One notes that 7 out of the 12 inventors with the highest values belong to the Pavia school.

Table 8 – First 10 values of *degree centrality*

<i>Ranking</i>	<i>Professor</i>	<i>Graduated at Pavia</i>	<i>d(n_i)</i>
1	NO	NO	37
2	YES*	YES	35
3	YES*	NO	29
4	NO	YES	28
4	NO	YES	28
6	NO	NO	24
6	NO	NO	24
6	NO	YES	24
9	NO	NO	22
10	YES	YES	21
10	NO	YES	21
10	NO	NO	21

Note: *Professor of the University of Pavia.

Table 9 – *Degree centrality* of the various categories of inventors of the first circle

<i>Mean value of degree centrality per-capita</i>	
30 professors + 140 inventors del first circle	7,5
Professors (30)	7,9
professors UniPv (5)	17,6
Not professors (140)	7,4
graduated at Pavia (39)	8,0
not graduated at Pavia (101)	7,2
Pavia school (47)	9,4

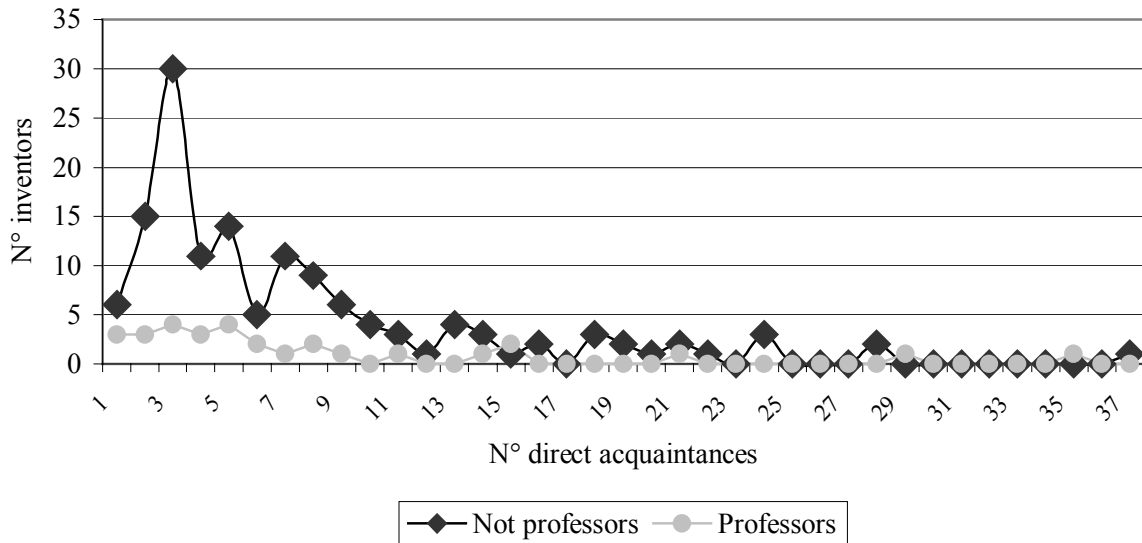


Figure 9.- Degree centrality: distribution of the number of acquaintances per inventor

Table 9 compares the different categories of actors. The values are similar to those of productivity (as was expected), merely the teams which produced a high number of patents without changing collaborators result slightly penalized. Moreover figure 9 shows that, unlike professors, the other inventors with few direct acquaintances are numerous. Among those who are not professors, the 39 ones who graduated at Pavia have more relationships than the others (since the first quartile has on average 18,6 acquaintances, as against 16,0 acquaintances of the other inventors).

Another concept of centrality of a node is *betweenness centrality* (Freeman, 1979). This concept expresses the extent to which a particular node lies “between” the other pairs of non adjacent nodes on their geodesics, having a function of gatekeeper for the connections of the actors in the network.

Our data permit us to compare the values of *betweenness centrality* only of patenting professors, since they are the only inventors of whom we know a two steps path. Again, the strategic role of the Pavia school emerges.

Table 10 – The highest values of *betweenness* of patenting professors

<i>Ranking</i>	<i>Professor UniPv</i>	<i>Graduated at Pavia</i>	<i>Betweenness</i>
1	YES	YES	40631
2	YES	NO	29431
3	NO	YES	21375
4	NO	NO	18101
5	NO	NO	7897
6	YES	NO	6797
7	NO	NO	4432
8	NO	YES	3937
9	NO	NO	1425
9	NO	NO	1425

3.5 The role of professors in training inventors

In order to capture the role of Pavia professors in training inventors, we analysed all the first patents (where first is meant in chronological sense) realised by the 170 inventors of whom we know all patents¹⁹. For every inventor we searched for the identity of the collaborators who, having previously already authored a patent, co-authored his first patent, assuming that they had a function of “masters”. Thus we inserted the data into UCINET asymmetrically, in order to get an arrow which originates from every “new-inventor” and is directed towards his co-authors who had a previous patenting experience. By counting the numbers of incoming arrows directed to Pavia professors, other professors and other actors who are not professors, we could compare the role played by these categories in training inventors.

Table 11 shows to what institution the 10 most important “masters” belong, ordering them on the basis of their *in-degree*, that is the number of arrows terminating at them, which corresponds to the number of actors who signed their first patent with them. The mean values of the various categories examined are also displayed. On average, the *in-degree* of inventors who are not professors is 3,2, of professors is 4,8 and of the 5 Pavia professors 10,6. The latter very high value is mainly due to the role of the stars (the first and the third ones in the ranking) who, involving young researchers in their activity of knowledge production, also played a particularly important role of educators.

¹⁹ Obviously this required a complete analysis of all 555 names of our database, since the “masters” of the 170 new inventors might be located also in the “second circle”.

Table 11 – First 10 values of *in-degree*

<i>Ranking</i>	<i>Professor</i>	<i>Graduated in Pavia</i>	<i>In-degree</i>
1	YES*	YES	24
2	NO	NO	17
3	YES*	NO	15
4	NO	YES	14
4	NO	NO	14
4	NO	NO	14
7	NO	YES	13
7	NO	NO	13
7	NO	NO	13
10	NO	NO	12

Note: *Professor of the University of Pavia.

Table 12 – *In-degree* of the various categories of inventors of the first circle

<i>Mean per-capita in-degree</i>	
Professors UniPv	10,6
Professors	4,8
Not professors	3,2

Figure 10 spots the inventors who graduated at Pavia, the 3 Pavia professors with a notable role of master (as is shown by the high number of incident arrows), a Pavia PhD student who starts to undertake a master role and a Pavia professor who did not play this role. We pointed out also the ties of the two professors who graduated at Pavia but then left the Lombard university: one notes that they realised their first patent with Pavia professors and later became important masters themselves.

With regard to the 74 inventors of the original complete network who graduated at Pavia, a good 36 realized their first patent with Pavia professors .

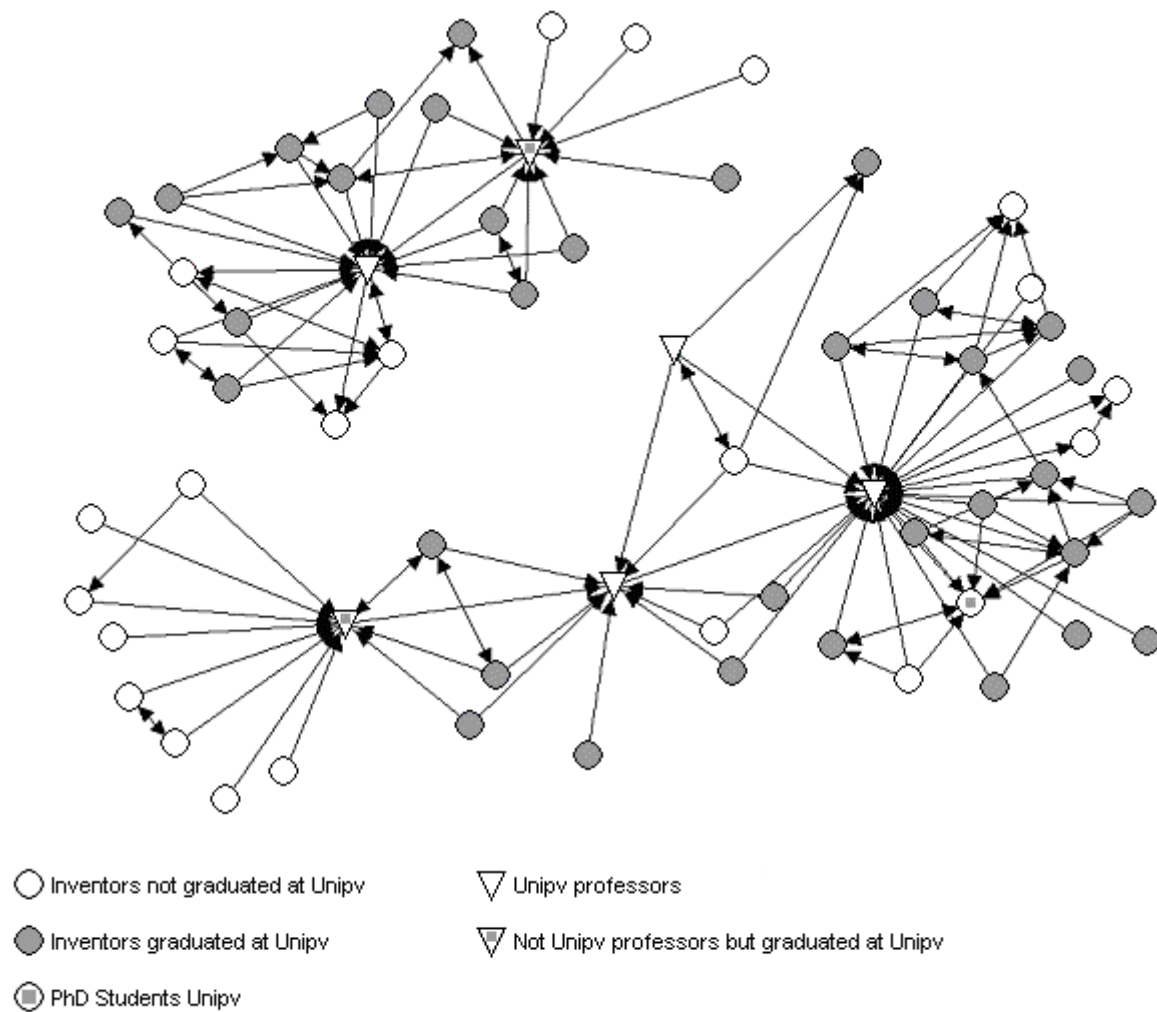


Figure 10

3.6 An example of ego-network of a professor

Thanks to the information obtained through the questionnaire filled in by patenting inventors, which we discussed in section 2.5, we could analyse the ego-network of Pavia professors of electronics with accuracy. By ego-network is meant the set of all (and only) the nodes that are directly linked with the social actor considered.

We show in figure 11 the most notable example of the collaborations that one of the two Pavia stars established during his persistent patenting activity and of the relationships that his collaborators set up between each other by participating to the teams including the professor.

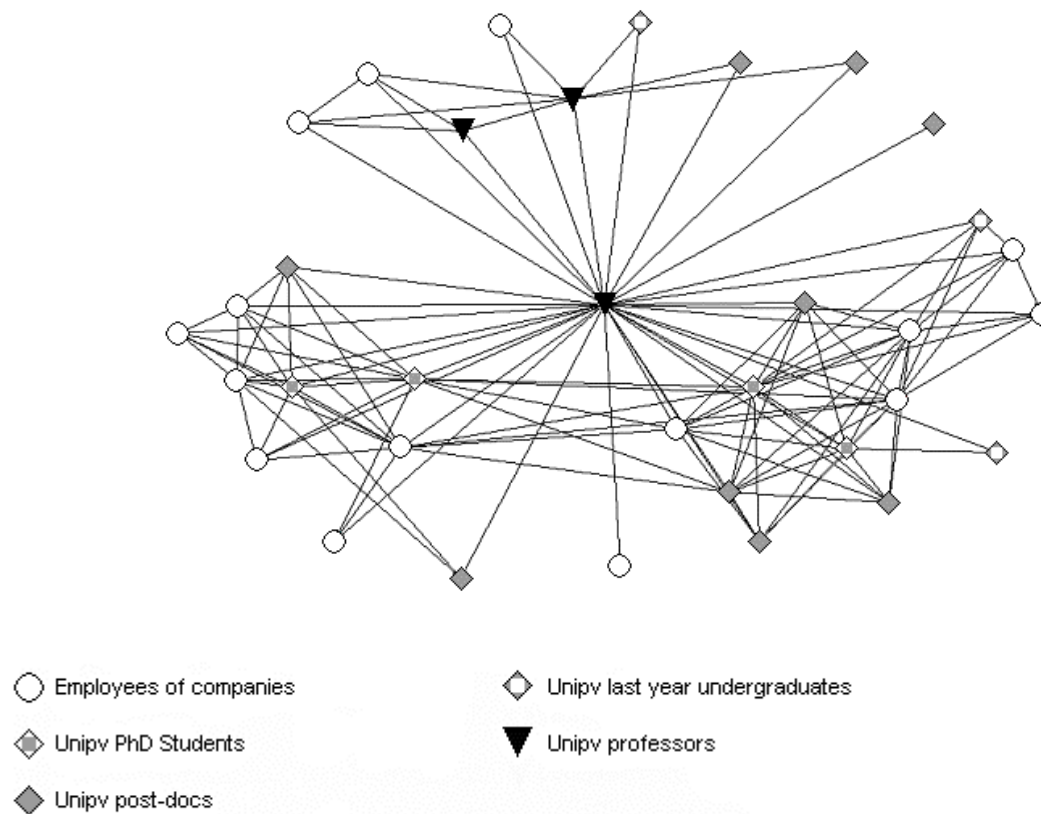


Figure 11

Pavia professors are represented with the 3 black triangles (the *ego* of the network is however only the professor at the centre of the figure), the other university insiders with the 16 diamonds and the industrial employees with the 15 white circles (we know that 5 of them graduated at Pavia, but to permit a clearer reading of the figure we preferred not to spot them). However, the total number of the actors involved is not 34, as it would seem, but 30, since 4 who changed qualification during their career are indicated twice. We find two PhD students, one last year student and one post-doc who became firm employees. This indicates that the research activities performed at the university by graduate students and post-docs are not meant only as first steps of the academic career, but also as the final phases of a high education which leads to industry. This outside mobility is important to support lasting relationships between university and industry²⁰.

Finally, in the figure one can appreciate that the professor is able to connect persons of different institutions (role of *spanner*). In fact there is no split between the personnel of the

²⁰ This is also confirmed by the analysis of the *ego-network* of other professors (see also section 3.2).

University of Pavia (the diamonds) and firm employees (the circles), but dense relationships (the lines connecting the points) tie the two sets of actors.

3.7. The scientific productivity of academic inventors compared with that of not patenting professors

The final issue considered is whether the production of patents diverts the activity of professors from their main institutional task, the creation of open knowledge with no restriction in use. To face this question we compared the scientific production of academic inventors with that of a control sample formed by not patenting professors²¹, resorting to the database *Web of Sciences*²² of the Institute of Scientific Information (ISI).

The results are extremely clear: academic inventors (and not only stars, as is shown by quartiles) publish much more than their not patenting colleagues (table 13). The Pavia school of excellence is particularly prolific also in this activity. The collaboration of professors with industry in the field of electronics is in fact fundamental to direct researches, to realize prototypes thanks to the access to productive technologies and to get the funding of fellowships for young researchers (Balconi, Centuori, in OECD 2004). Hence the academics who pursue it actively are in a better condition to produce new scientific knowledge, both quantitatively and qualitatively. In fact only the realization of prototypes permits to obtain the measures which are required to validate the theoretical hypothesis on the functioning of new electronic circuits. In general academics with no relationships with firms confine themselves to publish the results of simulations, without getting more robust evidence.

We also considered the *impact factor*²³: the difference of value of the journals where the two groups publish is not statistically significant. Moreover, this indicator might be misleading, since the publications of the sector deemed more important from the experts do not have a particularly high *impact factor*, due to their specificity. A more precise analysis on the scientific production should consider the number of authors of the articles (which varies

²¹ The sample è formed by 30 professors del sector of electronis randomly chosen among the “twins” of the 39 inventors as to age, academic position and university of affiliation.

²² ISI’s census of publications starts from the year 1990.

²³ The *impact factor* is defined by ISI as follows: “The journal impact factor is a measure of the frequency with which the ‘average article’ in a journal has been cited in a particular year. The impact factor will help you evaluate a journal’s relative importance, especially when you compare it to others in the same field. The impact factor is calculated by dividing the number of current citations to articles published in the two previous years by the total number of articles published in the two previous years.”

from 2 to 500) and the difference between letters and articles. Ours is only a preliminary examination of this issue, which clearly is worth more attention by future researches.

Table 13 –The scientific production of patenting professors compared with that of not patenting ones

<i>Categories of professors</i>	<i>N° publications p.c.</i>	<i>Q₁*</i>	<i>Q₂*</i>	<i>Q₃*</i>	<i>Q₄*</i>
Patenting professors (30) ¹	45,8	23,3	41	56	173
Not patenting professors (30) ¹	27,9	8,3	15	34,5	135
8 Pavia school patenting professors	67,25				
<i>Total N° of publications</i>					
Patenting professors (30)	1.374				
Not patenting professors (30)	838				
8 Pavia school patenting professors	538				
<i>Mean value (weighted with the number of articles) of the impact factor² of the journals that published the articles</i>					
Patenting professors (30) ³	1,84				
Not patenting professors (30) ³	2,16				

Notes: * Q₁, Q₂, Q₃, Q₄ are the number of publications that delimit the quartiles.

¹ t-test on the difference of the number of publications between the two groups significant at 0,95.

² *Impact factor* of the year 2002.

³ t-test lower than 0,95: the values of the difference of the *impact factor* is not statistically significant.

From our interviews to academic inventors, it emerges that patents may cause some delay to publications, but not to a worrying extent. However, also this issue should be more thoroughly addressed by further investigations.

On the basis of the information collected, it appears that the networks of collaboration between academic and industrial researchers, created to perform the researches funded by industry, are very useful and effective in diffusing and creating knowledge and that they do not lead to significant tensions between the contrasting reward systems of the two worlds (Dasgupta and David, 1994). In fact, both academic and industrial researchers gain “moral rewards” in participating (the reputation which derives from authoring publications and patents), besides the advantages mentioned above, while funding firms, seeking “material rewards”, improve their knowledge assets and enlarge their portfolio of patents²⁴. In other words, research contracts between firms and university departments are a tool suited to maintain a good balance between the different structures of incentives (David, Foray,

²⁴ Note that in the field of microelectronics patents are mainly used to make exchanges of intellectual property between firms, that permit to innovate without incurring the risk of infringing someone else's patent (Mazzoleni, Nelson, 1998; Hall, Ham, 1999).

Steinmueller 1999) and successful to improve the performance of participating institutions. A good research policy should favour these practices.

4. Conclusions

In this essay the count of USPTO patents assigned to firms and authored by university professors has substantially confirmed the results of previous investigations based on EPO patents, at least with regard to the single case that we have examined. Indeed, the role of university in the Italian national innovation system appears enhanced, since the overall number of USPTO patents of Italian (not academic) origin is lower than EPO patents. But above all, through the questionnaire filled in by Pavia academic inventors, it was possible to shed light on the fact that the realization of patents in the context of researches funded by firms and performed within academic departments involves also last years students working for their dissertation, fellows, technicians and PhD students who cooperate with professors: taking into account these collaborations, the role of the academy appears significantly increased.

In the second part, by applying the methodology of Social Network Analysis to the Italian network of academic inventors belonging to the scientific sector of electronics we could show very clearly the centrality and the role of main connector of a school of excellence, whose members we had been able to identify. Naturally, the use of patents and the focus on their co-authors was justified since electronics is a sector of applied research in which scientific and technological activities are even difficult to distinguish (Meyer 2000).

But the same method can be applied to other fields, on the basis of *co-authorships* in publications or to analyse the networks emerging from scientific citations. The importance of groups of excellence in giving rise and connecting wide epistemic communities cannot be understated.

By focusing on the social network it becomes possible to stress other important aspects of the activity of university professors, beyond the production of codified knowledge and traditional teaching: giving rise to and connecting epistemic relationships is crucial to transfer know-how and uncoded knowledge and to stimulate firm researchers. The most prominent professors in the production of open knowledge are the most active also in performing these functions. Moreover, a large part of the epistemic relationships among actors persist over time.

In conclusion, SNA allows an analytical treatment of the concept of *invisible colleges*, and the measurement of their dimensions and structural characteristics. The principal component of the network centred around the school of excellence, depicted in this work, is a real *invisible college*, where the academic and technological world are interpenetrated.

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