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Academic inventors as brokers☆

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ABSTRACT

Academic inventors are university scientists who appear as designated inventors of patents owned either by business companies, academic institutions or individuals. We analyse their relationships with co-inventors, who may be either academic colleagues, students, or, very often, industrial researchers. Gould and Fernandez's (1989) taxonomy of 'brokerage' roles is adjusted to patent data, and complemented with information drawn from both academic inventors' publications and replies to a short questionnaire. Only very few academic inventors are found to hold brokerage positions. Such inventors have a large number of patents, a strong publication record and a higher-than-average share of patents held by companies, rather than universities. Relationships of academic inventors with co-inventors from industry are weaker and less likely to be maintained than those with co-inventors from academia. Academic inventors in gatekeeping positions (between university and industry) maintain the strongest ties with all types of co-inventors.

1. Introduction

Recent research on university–industry technology transfer has given a great deal of attention to the theme of university patenting. In the past few years, European economists and other social scientists have identified a large number of so-called 'academic inventors', namely academic scientists who appear as designated inventors of patents whose assignee is not necessarily a university or a public research organization, but can also be the scientist himself or, most often, a business company (see surveys by Geuna and Nesta, 2006; Verspagen, 2006; Foray and Lissoni, forthcoming).

Most patents signed by academic inventors are co-authored by other inventors, who can either be their colleagues or students, or else researchers employed by the company that owns the patent. The relationship between academic inventors and such co-inventors is of great interest, in that it may help us to understand what role the former play in transferring knowledge and other resources to and from industry, or in putting students in contact with prospective employers (and possibly keeping in touch with them throughout their careers). In order to investigate this issue, we need to answer a number of empirical questions: How many co-inventors of academic patents are industrial researchers and students *vis-à-vis* academic colleagues? Are academic inventors instrumental in linking (otherwise unrelated) colleagues and students with researchers from industry, or in bringing together (otherwise unrelated) industrial researchers from different teams or companies? Do academic inventors entertain stable collaborations with their co-inventors, or is the interaction limited to short-lived projects (those that have produced the observed patents)? Do the answers to all these questions change with the type of co-inventors (academic scientists, industrial researchers, or students) and/or with the personal characteristics of the academic inventors (age, academic rank, discipline or scientific status)?

Answers to these questions may also provide some clues to the nature of the exchanges between inventors (academic and non-academic). Co-invention necessarily implies some amount of information sharing, but this may vary a lot. At one end, information sharing may be limited to the practicalities of the underlying research project (as when a rigid division of labour occurs, with lim-

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ited diffusion of scientific or technical knowledge). At the opposite end, it may stretch to knowledge diffusion, as when the invention results from a joint research effort and deep intellectual exchange. In addition, other resources may be exchanged by co-inventors, either substantial (access to research funds or instruments, such as data or equipment) or symbolic (such as mutual recognition of the contribution given to the research, from which visibility and prestige may follow).

In this paper, we build upon the relational analysis of Italian academic inventors presented in Balconi et al. (2004), by integrating a subset of the original data with the results of a short questionnaire, and with data on the scientists' publication records and CVs. Our objective is to answer all the questions listed above, and to do so by relying on sociometric measures comparable to those used elsewhere in the literature. In order to do so, we adapt Gould and Fernandez's (1989) definitions of brokerage roles to our co-inventorship data. This allows us to measure the extent to which academic inventors stand in between otherwise unrelated co-inventors from university and/or industry. We find that only a minority of academic inventors play important brokerage roles, and that scientific productivity, intensity of patenting activity, and the type of patent assignees (companies vs. universities or individuals) are all correlated to such roles. We also find that only a minority of academic inventors entertain further research collaboration links with former co-inventors, who mostly come from the university ranks. Finally, we find that academic inventors who occupy a 'gatekeeper' position, in between university and industry, maintain stronger ties with co-inventors from both realms, whether for research collaboration or mere information exchanges.

In Section 2 we provide summaries of the distinct, though related literature on academic inventors and networks of inventors, technological gatekeepers and brokers, and brokerage measurement in social network analysis. In Section 3 we describe our data and methodology. In Section 4 we present our quantitative results, on which we also comment in the light of illustrative biographical information we collected on the academic inventors who stand out most prominently as brokers. Section 5 concludes.

2. Background literature and conceptual issues

2.1. Academics in networks of inventors

Research on university patenting in Europe has been very intense over the past decade. Apart from the studies by Geuna and Nesta (2006) and Verspagen (2006), more recent research has been published on Germany (Czarnitzki et al., 2007), Norway (Iversen et al., 2007) and Italy, France and Sweden (Lissoni et al., 2008). All this evidence suggests that European universities, despite not having such large patent portfolios as their US counterparts, do contribute remarkably to their countries' patenting record *via* their scientists' inventive efforts (Lissoni et al., 2008). Most patents covering inventions by European academic scientists, however, do not belong to universities, but to business companies. Some of them derive from contract research or consulting, while others are the result of research partnerships between companies and universities, with the latter often leaving the IPRs over the research results to the former. The institutional specificities of European academic systems are such that many universities have either little interest or little ability to bargain with both their own staff and companies, in order to reclaim or to share the IPRs over academic inventions, in comparison to the US public and (especially) private academic institutions.[1]

Several recent enquiries have focused on the technological characteristics, ownership patterns, and the value of what have now become known as 'academic patents', that is, patents whose inventors include at least one academic scientist, irrespective of the assignee.[2] Other lines of enquiry focus not so much on the patents, but on their inventors. Inventors can be interviewed, their CVs or publications can be retrieved, and analyses can be performed on the determinants of their productivity, and on their mobility in space or across organizations. Recent investigations, in particular, have found that academic inventors are very productive scientists, whose productivity further increases after patenting (see survey by Franzoni and Lissoni, forthcoming).

Finally, patent data, when reclassified by the inventor, can be seen as a key source of relational data, which may cast light on the nature of the exchanges among co-inventors and, by implication, between researchers from university and industry. Patents authored by two or more co-inventors, in fact, are instances of collaboration: co-inventors of one or more patents can be safely presumed to know each other and to have exchanged some information (at the very least, the information necessary to keep the research going; we will say more on this later[3]). Based on this assumption, one can build networks of inventors where the latter are represented by nodes, and patents are ties between them. Balconi et al. (2004) build a network of Italian inventors from data on patent applications registered at the European Patent Office between 1978 and 1999, and find that academic inventors tend to occupy more central (in-between) positions in the network.[4] Lissoni and Sanditov (2007) find that the same results hold for France and Sweden. Note that neither study finds that all academic inventors stand in central positions (high degrees of in-betweenness always being a property of few nodes), but that, on average, academic inventors have higher centrality scores than other inventors. However, for both inventors and non-inventors, average values are strongly dependent on a few individuals with

[1] US universities have been entitled to IPRs over federally funded research since 1980, with the introduction of the Bayh–Dole Act, which has been imitated only recently by some European countries. In addition, some of the latter for a long time held (or still hold now) the so-called 'professor's privilege', by which all inventions produced by university professors do not belong to their employers (as is the norm with business companies and their R&D staff), but to the professors themselves, who dispose of them freely. Even in countries where this 'privilege' has never existed, university professors are civil servants under direct control of the State, whose disclosure duties towards their universities are rather unclear. More on this can be found in Lissoni et al. (2008). Differences exist between European universities, however: yet-to-be published data from ongoing research projects suggest that Dutch and British universities enjoy more autonomy than other European academic institutions and retain a higher share of patents over their scientists' inventions.

[2] Crespi et al. (2006) found that inventors' own estimates of the economic value of their patents are not affected by the ownership of the patent, that is, they find no evidence that, by retaining the property of their scientists' inventions, universities would do a better job than companies in turning patents into valuable assets.

[3] Readers who are familiar with co-authorship data know that, when it comes to publications from big-science disciplines, the assumption of mutual knowledge between authors may be untenable. Such readers may be tempted to extend their doubts to co-inventorship in patents. However, co-inventorship figures are no match for co-authorship ones. If we look at the data used for this paper, the maximum number of inventors per patent is 21, which is reached by one patent only; but if we look at the papers published by the academic inventors in the dataset, there are 23 among them with over 21 authors, two of which have 337 and 517 authors respectively. Publications with very large numbers of authors result from the collaboration of several research teams, each one of them related to the others *via* the more senior members only (which is to say that most co-authors may not have even met). Moreover, these publications are just summaries of large research programmes, the results of which are then detailed in several publications with fewer authors (those responsible for the specific results). Patents, on the contrary, cannot be summaries of anything, but must describe specific inventions to which all inventors have to be somehow related (albeit not necessarily to the same extent, and not always without disputes). Further comparisons between co-inventorship and co-authorship data can be found in Lissoni and Montobbio (2008).

[4] We will come back to technicalities, such as the meaning of in-between centrality (in-betweenness), and related references in Section 2.2.

high values, as typical of all networks based upon bibliographic data. Breschi and Catalini (forthcoming) investigate jointly the networks of inventors and the networks of authors of patent-cited scientific literature: they find that individuals who are both authors and inventors (among whom they find a large share of academics) play an important role in both networks, where importance is once again measured by centrality scores. Breschi and Lissoni (2005, 2009) find that close ties between inventors (of which co-inventionship is the best example) are good predictors of citation links between patents. This suggests that, to some extent, co-invention ties allow for some degree of knowledge diffusion.

Network analyses based purely on archival data such as patents, however, cannot explore in much greater depth the nature of the relationship and of the resources exchanged between inventors, for at least three reasons.

First, the identity of co-inventors of academic patents is not always clear; they may either be industrial researchers (most typically, members of the patent assignee's R&D staff), graduate students or academic colleagues, some of whom may have possibly retired or left the university.[5] Information on such identity is necessary to understand whether the central position of academics in the network of inventors, as found in the literature, is due to the transposition into the technological realm of the relational structure of academic science, or to some academic inventors' ability to span boundaries between academic and industrial research.[6] In the first case, we would observe that academic inventors who occupy central positions do so because they stand in between other academics. In the second case, we would observe academic inventors standing also in between industrial researchers and students. An academic scientist's position in-between co-inventors from the same professional group (other academics) or from different ones (students or industrial researchers) may be captured by various notions of brokerage, upon which we expand below.

Second, patent data do not provide information on the exact nature of the exchanges occurring between co-inventors during the inventive process (or at the research stage that often precedes it). Co-invention necessarily implies some amount of information sharing, but this may vary a lot and it may also be supplemented or traded for other types of resources such as financial or cognitive ones (data, instruments, or key research questions). Moreover, recognition of an individual as a co-inventor is by itself a symbolic resource which can be traded between members of a research team. Financial or cognitive resources may be exchanged between two academics, but also between an academic and a company, whose researchers will possibly join the research team and appear as co-inventors.[7] As for symbolic resources, Lissoni and Montobbio (2008) find (indirect) evidence that members of research teams who are responsible for both publications and academic patents negotiate over which members are worthy of recognition as authors or inventors or both; and that such decisions depend both upon evaluating the team members' scientific contribution to the research and on the team members' seniority and scholarly prestige. This suggests that recognition of co-inventorship may be obtained in exchange for a researcher's contribution as measured not only by the knowledge he/she has contributed or produced, but also by the organizational effort or the overall prestige and visibility he/she may have provided. This brings us back to the identity of co-inventors, relative to that of the co-inventors: industrial researchers may be signed in as co-inventors not so much for their knowledge contribution, but in exchange for the resources their companies may provide; students may be included in patents only when their knowledge contribution has been so extensive that excluding them would seem like an abuse. The relationships between co-inventors also matter in this respect and again we will return to this in the section below.

Third, the duration of social ties established during the co-invention experience may reveal the nature of the exchanges that occurred during that experience and, more importantly, of the exchanges that will or will not follow. Presumably, co-inventing experiences which imply a deep intellectual exchange (such as true scientific partnerships) will result in more durable ties, with further instances of collaboration; less so for convenient arrangements for the exchange of heterogeneous resources (symbolic or material). Note that participants in the same co-invention experience may entertain different relationships, according to their identity, which will result in different durability and intensity of their future exchanges. Durability and intensity may also depend upon the number of ties an academic inventor may have to manage, that is, how rich his/her personal network is. Once again, this brings us back to the notion of brokerage, and the associated notion of gatekeeper, to which we now turn.

2.2. Brokerage, gatekeeping, and innovation

Terms such as 'brokers' and 'gatekeepers' have long been used in sociology and organization theory, either with reference to the innovation process or to more general economic and/or political transactions. Within the field of organizational studies of innovation, Allen and Cohen (1969) introduced the notion of technological gatekeepers in order to describe individuals within R&D units who contribute highly both to the internal circulation of information and to the provision of access to external information sources. Subsequent research has found that such gatekeepers are highly competent individuals, who tend to exchange information more frequently among themselves than with less competent or more peripheral members of the same organization (Allen et al., 1979; Tushman and Katz, 1980; Tushman and Scanlan, 1981; Brown and Utterback, 1985). These studies describe the gatekeeper's role as necessary whenever organizations or units within organizations tend to develop an idiosyncratic language and knowledge base, which makes internal communication effective at the cost of limiting most organization members' understanding and appreciation of external resources, especially under conditions of technological uncertainty. These conditions are more likely to occur in development units rather than more research-oriented ones, possibly because scientists (who populate the latter) make use of more universal notions and languages than technologists (who populate the

[5] Archival data offer only incomplete information, as they list the inventor's address (most often the home address) but no information on the nature of the relationship with the assignee (which may be of employment, as with most industrial researchers, or consultancy/collaboration, as with most academic scientists and students). Subsidiary information on the inventors' affiliation derived from scientific publications may be of help, but only for those inventors who publish and in any case, it does not allow a distinction to be made between university employees and students.

[6] The aggregation of scientists around a few selected individuals, such as the pioneers of a research field or discipline, is a common finding of a well-established line of literature, which applies social network analysis to both archival data (from publications) and sociometric questionnaires. Note that such centralization, however, is not as extreme as that resulting in star graphs, and does not impede different aggregations of scientists from being connected one to another via some of their members (most often, the central ones). Classic references are Crane (1969) and Mullins et al. (1977). For a recent survey, see Zuccala (2006). For a discussion framed within the novel literature on small worlds, see Newman (2001).

[7] On the exchanges of resources (both material and cognitive) between scientists and industry, the classic reference is Rosenberg (1982). Some recent econometric evidence suggests that academic inventors, besides being highly productive scientists, further increase their productivity after engaging in patenting, a result which is widely interpreted as deriving from access to further resources obtained in exchange for the IPRs over the invention (Azoulay et al., 2006; Breschi et al., 2007).

former).[8] More generally, the concepts of technological gatekeeping and brokerage have provided insights in a number of loosely related fields such as diffusion and technology transfer, innovation policy and management, and innovation systems. This success, however, has contributed to making the use of the associated terminology both general and somewhat loose, gatekeeping or brokerage functions often being associated with all sorts of individuals and organizations in intermediary positions (Howells, 2006).

On the contrary, social network analysis has contributed to diffusion of the notions of 'broker' and 'gatekeeper' outside the boundaries of innovation studies by associating them with the operational concept of in-betweenness centrality. In any network (either social or physical, direct or indirect), a node *j* is said to stand in between two other nodes *i* and *z* if the shortest path between *i* and *z* passes through *j*. Measures of in-betweenness for node *j* are therefore based upon counts of how many shortest paths between any pair of nodes in the network pass through *j* (Freeman, 1979). Building on this operational tool, the sociological literature has searched for 'brokers' and 'gatekeepers' in a number of processes, which take place among individuals and/or organizations. Particular attention has been devoted to the economic or political rents that 'brokers' and 'gatekeepers' can enjoy thanks to their position. To the extent that social ties are seen as carriers of information or other resources, an in-between agent can take advantage of his/her position as controller of information and resource flows in many ways, which have been the subject of much investigation (for an extensive survey and discussion, see ICC, 2008; for a theoretical treatment of the related causality problems, see Ryall and Sorenson, 2007). In-between agents are even more relevant when the network they belong to is fragmented across different affiliation groups, as happens with citizens in the same town who belong to different religious or ethnic groups or (in our case) researchers in a given technological field who belong to different types of organizations (university staff or students, or industry). In this case, central agents may find themselves in between not only two other agents, but two entirely different groups of people, whose chances of communicating or trading resources in the absence of the in-between nodes are very few. Building upon this, Gould and Fernandez (1989) proposed a set of measures which develop further the general notion of 'in-betweenness' (as described above), by differentiating it according to the affiliation of the nodes involved in the considered path. In particular, Gould and Fernandez apply the in-betweenness measure to *j*'s (direct) ego-network, and count separately the shortest paths between any two nodes *i* and *z* passing through *j*, according to the affiliations of the three nodes involved in the path. In this way they obtain five different in-betweenness scores for as many positions as *j* can take[9].

- Node *j* is said to act as a 'broker' between any two nodes *i* and *z* whenever such nodes belong to the same affiliation group, and this group is different from that of *j*;
- Node *j* acts as a 'gatekeeper' when a path leads from *i* to *z*, and *j* and *z* belong to the same group, which is different from that of *i* (*j* is said to act as a 'representative' of *z* whenever the path runs the opposite way);
- Node *j* acts as a 'coordinator' when all three nodes *i*, *j* and *z* belong to the same group, and as a 'liaison' when each of them belongs to a different group.[10]

A number of papers have been published, which make use of Gould and Fernandez's methodology and find that actors in brokerage positions may enjoy strategic advantages in a number of activities, ranging from the political to the entrepreneurial (Fernandez and Gould, 1994; Taube, 2004). Data constraints do not allow us to extend our analysis in this direction: we do not have any data on academic inventors' careers after the patenting experience, or on their income or extra-academic activities. However, we can settle for a more descriptive, but quite informative exercise that will help us to identify the characteristics of academic inventors who act as brokers, gatekeepers, coordinators, or liaison, and to understand the nature and duration of the exchanges between them and their co-inventors.

3. Data and methodology

Data used in this paper come from the integration of three different sources: a database on Italian academic inventors, from Balconi et al. (2004); information gathered from a survey questionnaire submitted to a sample of these academic inventors; and data on the publication records of these same inventors, obtained through the ISI-Web of Science database. Some complementary biographical information on selected academic inventors has also been retrieved from e-mail exchanges with them and from web resources.

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[8] More recent studies have explored other figures of knowledge intermediaries, such as 'technological brokers' within invention-by-design processes (Hargadon and Sutton, 1997) and 'knowledge transformers' (Harada, 2003).

[9] Node *j*'s ego-network is a subset of the overall network that comprises only the nodes in direct contact with *j* (to which we can also refer as 'ego'), plus the ties among such nodes and the ties between them and ego. Ego will result in being in-between any two nodes to the extent that such nodes are not connected to each other by any direct tie, that is, they reach one another only through ego (or through other nodes, but with paths no longer than the one crossing ego). One might worry about the loss of information due to choice of considering only ego-networks, but such a loss is not great and there are some advantages. By only considering ego-networks, we disregard all paths between nodes in each ego-network that either do not consist of direct ties or pass through ego. This amounts to ignoring whether any node outside the ego-network stands in the same position as ego between the nodes in the ego-network, but this does not alter our calculations of ego's centrality. Exclusive focus on the ego-network also forces us to disregard all paths running through ego which connect nodes outside the ego-network, which means that we choose to concentrate only on short-distance paths crossing ego (more precisely, we concentrate exclusively on two-step paths; this would have consequences if we wished to find a correlation between an agent's position and the rent he/she may derive from it, as explained by Ryall and Sorenson, 2007; but this is not the case in this paper). However this does not amount to a great loss of information, since no node can occupy a highly central position in the overall network without also being central to its ego-network; and there is reason to believe that, when it comes to diffusing information or granting access to resources, it is short-distance paths that matter most (on the irrelevance of long-distance ties for diffusion, see Breschi and Lissoni, 2005, 2009; on the close correspondence between centrality measures based upon ego-networks and complete networks, see Marsden, 2002). Concentrating on ego-networks has the advantage of greatly simplifying the task of classifying the various in-betweenness positions, since the shortest paths considered for measurement never touch more than three nodes. To understand this point, consider the case of a node *j* standing between two nodes *i* and *z* separated by three steps. This would imply dealing with a path touching upon four nodes (*i*, *j*, *z* and another node, say *w*, standing either in between *i* and *j* or in between *j* and *z*): how would one classify *j*'s position with respect to this path if its affiliation coincided with that of *i* and *z*, but not with that of *w*?

[10] Gould and Fernandez also propose a standardized version of these measures, by which the number of each type of brokerage position taken by node *j* is divided by the expected number of positions the same node would take if its ego-network were a random one. Such standardized measures can be used to compare nodes with ego-networks of different size and group composition. However, this is not the type of exercise we conduct in this paper, so we will rely upon the absolute measures. Another important difference between Gould and Fernandez's original paper and our application is that the former dealt with a directed graph (derived from a sociometric survey on information exchanges), while we deal with archival data, from which only undirected graphs can be obtained (see more on this in Section 3). Gould and Fernandez's measures are now available on most software packages for social network analysis, such as *Ucinet* and *Peek* (both used for this paper), and their handbooks provide further clarification on the related algorithms.

Table 1
Italian university professors in 2000, selected fields.

Field	Professors, active in 2000	of which: academic inventors, no. and (%)
Chemical Eng. & Materials Tech.	355	66 (18.5)
Pharmacology and Pharma. Sciences	613	84 (13.7)
Biology	1359	78 (5.7)
Electronics & Telecom	630	73 (11.6)
Total	2957	301 (10.2)

Source: Breschi et al. (2007).

3.1. Data

The database on Italian academic inventors originates from the EP-INV database produced by CESPRI-Università Bocconi, which contains all EPO applications published since 1978, reclassified by applicant and inventor; and from a list of university professors of all ranks (from assistant to full professors; we will refer to this as PROFLIST). PROFLIST originates from a complete list of Italian professors and researchers who, in 2000 and 2004, held a post in a scientific or technical discipline in an Italian university (including medical and engineering schools). Such a list was provided by the Italian Ministry of Education and contains information on individual characteristics of the scientists (age, affiliation, academic rank, discipline). Academic inventors have been identified by matching the names and surnames of inventors in the EP-INV database with those in the PROFLISTs, and then checking the identity of the matches through e-mail and telephone, in order to exclude homonyms.[11]

In this paper we focus on a subset of the database, which includes professors (full, associate, and assistant) from the four disciplines with the highest share of academic inventors over the total number of professors in Italy, namely Chemical Engineering (including technology of materials, such as macromolecular compounds), Biology, Pharmacology, and Electronics and Telecommunications. We also limit our analysis to professors who were already in post in 2000, with a total of 301 academic inventors, who account for around 10 per cent of Italian professors active in the selected disciplines in 2000 (Table 1).

As shown in Table 2, most patents signed by the selected academic inventors are owned by business companies, rather than 'open science' institutions (such as universities and public research organizations); a minority of patents are assigned to individuals, most often the professors themselves, or a relative. The ownership patterns vary across the professorial disciplines, with Biology standing out as the one with the highest percentage of patents assigned to open science institutions and individuals.

Publication data were collected from the 1975 to 2003 on-line version of ISI's *Science Citation Index* for all 308 academic inventors in the selected fields. A more detailed description of these data can be found in Breschi et al. (2007).

Finally, we contacted our academic inventors in order to ask them questions related to the various aspects of the research behind the observed patents. The questions most relevant for this paper were those related to the identity of and the relationship with the co-inventors. Academic inventors were asked whether:

1. they actually knew the co-inventors listed together with them on the patent document (all answers were positive);
2. these co-inventors were academic colleagues, industrial researchers or students, at the time when the patent was signed;
3. they were still in touch with their co-inventors, either for research purposes or information exchanges (more on this in Section 4.2).

We successfully interviewed 156 academic inventors (51 per cent of the total), who provided information on 741 of their 771 co-inventors (interviewees who had worked with many co-inventors sometimes refused to provide information on all of them, since this would have prolonged the interview too much). However, due to the fact that several co-inventors signed patents both with academic inventors who agreed to be interviewed and with some who did not, we have information also on the co-inventors of 29 of the latter, for a total of 185 academic inventors. The first two columns of Table A1 in the appendix compare the percentage distributions of all academic inventors and respondents by scientific age, discipline, number of patents, and scientific productivity. Differences are not substantial, but academic inventors born after 1950, active in Electronics & Telecommunications, and with just one patent tend to be over-represented in the respondents' sample; the opposite holds for academic inventors born before 1941, active in Pharmaceutical research, and with two or more patents. Inventors with zero publications tend to be under-represented in the respondents' sample, which explains the slightly higher values for the mean and median productivity of respondents vs. all academic inventors. The average number of co-inventors per patent is practically the same for respondents and for the whole sample (4.94 and 4.69, respectively).

3.2. Methodology: brokerage positions from patent data

Once the group affiliation of the co-inventors has been established, one can then calculate the number and type of brokerage positions of academic inventors. However, there are three difficulties in the way of a straightforward application of Gould and Fernandez's methodology. All derive from the fact that networks of inventors are based upon archival data, rather than sociometric questionnaires.[12]

First, a questionnaire aimed at gathering network information can phrase questions in such a way that the resulting ties between actors are direct (for example: "who do you rely upon for information among your friends?"; information requests may go from j to z, and not be reciprocated; the same applies to flows of other types of resources). This is not the case with patents: when j and z are found to be co-inventors of the same patent, there is no way we can tell who was asking information or help from whom, and whether he/she reciprocated. No directed graph can be built.

Second, when n inventors have worked on the same patent, they immediately form a clique of size n. If $n=3$ this is a triangle whose vertices (nodes) are all connected to each other: no node is in between the other two. This means that counting how many times an academic inventor stands in between two co-inventors

[11] The database, first used by Balconi et al. (2004), has been recently updated and merged with a similar database for other countries, under the name of KEINS database; on this occasion, a technical paper has been produced to which the reader may refer for clarification on the methodological details (Lissoni et al., 2006). It is this version of the database we use here. The major limitation of the database is that it includes only those professors and researchers who have passed a competitive examination for a tenured position (from now on, we will refer to them simply as 'professors'). Thus our data miss the large number of fixed-term appointees who, at the time, had been working in one or more universities for one or more years, as well as all the PhD students, post-doc fellows, and technicians. In the current Italian system, assistant professor (called 'researcher') and associate professor positions, despite being only the first two steps of an academic career, are not offered as fixed-term appointments, but as tenured ones. The main differences with the position of full professor are in salary and administrative power and responsibilities.

[12] See Burt (1983) for a more general treatment of the advantages and disadvantages of using archival data, as opposed to questionnaire results, as input for social network analysis.

Table 2
Ownership of academic inventors' patents[a] by type of applicant and field; no. (%) of patents.

	Business companies	'Open Science' institutions[b]	Individuals[c]	Others (n.e.c.)	All applicant types
Chemical Eng. & Materials Tech.	125 (78.1)	18 (11.3)	15 (9.4)	2 (1.3)	160 (100)
Pharmacology	192 (85.0)	24 (10.6)	10 (4.4)	–	226 (100)
Biology	91 (54.5)	43 (25.7)	30 (18.0)	3 (1.8)	167 (100)
Electronics & Telecom	199 (81.9)	28 (11.5)	13 (5.3)	3 (1.2)	243 (100)
All fields	607 (76.3)	109 (14.2)	68 (8.5)	8 (1.0)	796 (100)

Source: EP-INV-DOC database.
[a] Patents owned by more than one applicant were counted more than once.
[b] Universities, public laboratories and government agencies; both Italian and foreign.
[c] Same applicant's and inventors' names.

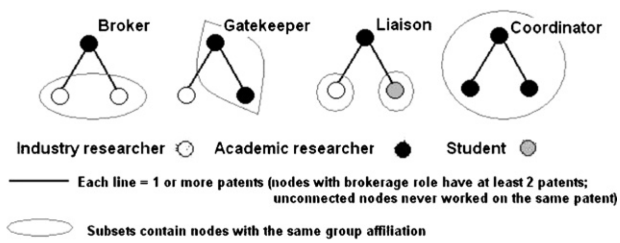

Fig. 1. Brokerage positions: definitions.

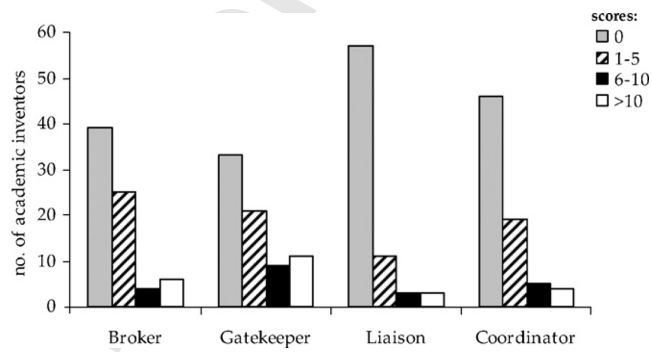

Fig. 2. Distribution of brokerage scores.

Table 3
No. of academic inventors, by no. of patents signed.

No. of patents per inventor	No. of inventors
1	111
2	22
3	15
4	9
5	11
6–10	9
11–20	6
21–30	2
All inventors	185

(as required by Gould and Fernandez's method) makes sense only for academic inventors with at least two patents.

Last, standardized brokerage measures, based upon the ratio between the observed instances of in-betweenness and the hypothetical instances for a random ego-network, do not make sense. In fact, academic inventors' ego-networks can never be random, because they are the sum of several complete subgraphs, one for each patent signed by the academic inventor.

The first problem can be confronted simply by adapting Gould and Fernandez's methodology to our data, which implies giving up some of the nuances of the original definitions of brokerage positions. Fig. 1 reports the definitions we will use in this paper.

Academic inventors find themselves in the position of brokers whenever they stand in between two industrial researchers (or, more rarely, students). They act as gatekeepers whenever they stand in between an industrial researcher (or a student) and an academic researcher[13]; and as liaisons when they stand in between an industrial researcher and a student. Finally, they act as coordinators whenever they stand in between two members of their own affiliation group, that is, two academic researchers.

As already said, the second methodological problem mentioned above forces us to restrict our analysis only to academic inventors with at least two patents. They are a minority in our sample – only 74 out of 185 (see Table 3). As explained above, academic inventors in our respondents' sample are slightly under-represented, due to the fact that several academic inventors with multiple patents refused to answer or to complete the questionnaire (which for them was much longer than for others, due to the longer list of co-inventors about whom we asked information).[14]

As for the last problem, the only solution we have found so far is to consider the absolute number of brokerage positions taken by each academic inventor, and to control for the number of patents signed by the inventor any time we use the latter's brokerage score as an independent variable in a regression.

Fig. 2 provides some summary statistics on the distribution of brokerage scores for the 74 academic inventors considered. Most academic inventors do not play any brokerage role at all, that is, they are never in between any two co-inventors in their ego-network; this is particularly true for 'liaison' scores, since students are a rare presence in the set of co-inventors.

The age and seniority of academic inventors also contribute greatly to explain their brokerage scores. From Table 4 we see that it is only full professors who achieve the highest scores. However, age and seniority are also correlated with the number of patents held by each academic inventor, and possibly with other variables highly correlated to the observed brokerage scores. Therefore, in the next section, we move on towards a more systematic exploration of the characteristics of academic inventors with high brokerage scores. Note that, for the sake of brevity, we will use expressions such as 'brokerage scores' or 'brokerage positions' in order to refer to the

[13] In the absence of direction, it is impossible to distinguish between gatekeepers and representatives.

[14] The last column of Table A1 in the appendix reports the percentage distribution of questionnaire respondents with more than two patents by scientific age, discipline, number of patents, and scientific productivity. With respect to all respondents we note that academic inventors from Biology are under-represented, while those in Electronics and Telecommunications are over-represented; younger inventors are also under-represented in favour of older ones. As for scientific productivity, the median and mean values are respectively higher and lower for all respondents than for respondents with more than one patent; the latter include a lower share of inventors with two to five publications per year, and a higher share of inventors with either less than one or more than five publications per year. This change of distribution explains the higher variance in the productivity of respondents with more than one patent than in all other samples, and suggests that outliers may affect considerably the estimation results of the econometric exercises of Section 4.

Table 4
Brokerage scores and academic seniority.

Score	Broker		Gatekeeper		Liaison		Coordinator	
	Full	Assoc. & Assistant	Full	Assoc. & Assistant	Full	Assoc. & Assistant	Full	Assoc. & Assistant
0	45.5	63.3	40.9	50.0	77.3	76.7	54.5	73.3
1–5	31.8	36.7	20.5	40.0	11.4	20.0	25.0	26.7
6–10	9.1	–	15.9	6.7	4.5	3.3	11.4	–
>10	13.6	–	22.7	3.3	6.8	–	9.1	–

complete set of broker, gatekeeper, coordinator, and liaison scores we can measure for any inventor.

4. Results

4.1. Determinants of brokerage positions

In this section we examine how many of the 74 academic inventors in our database with more than one patent hold brokerage positions. On the basis of their biographical information and their publication record, we also produce a profile of those with the highest brokerage scores.

In order to do so, we first run a regression of various measures of brokerage over a number of characteristics of the academic inventors, such as their observed scientific productivity, age, academic rank (full, associate or assistant professor), and disciplinary affiliation. Productivity is measured as the average number of articles per year published in academic journals listed on the ISI-Web of Science database between an academic inventor's 24th birthday (a conventional date for the start of his career) and 2003 (when the publication data were collected). Alternatively, a 'late-productivity' measure is similarly produced, which spans only the last 10 years of the academic inventor's career.

When running the regression, we control for the number of patents signed by the academic inventors, which by construction, are positively correlated to the brokerage scores. However, we distinguish between patents owned by business companies, open science institutions, and individuals, as we expected only the former to be signed by co-inventors from the 'industrial researcher' affiliation group.

By no means can the proposed regression be interpreted as an explanatory one, as no causation link can be assumed to run from the independent variables to the dependent ones. In order to 'explain' the brokerage position reached by any academic inventor, one would need to observe the accumulation of social ties (with co-inventors) over time, and find a way to solve two problems of endogeneity in the regression. The main problem is that fixed effects may explain a lot: highly productive professors have a higher probability of producing not only papers, but also patentable inventions; and those who have many patents have a high probability of recording a high brokerage score.

However, one can interpret our regression coefficients as a set of partial correlation indexes, which help produce a portrait of who acts as a broker (or gatekeeper, or coordinator) among academic inventors.

We can first look at Table 5, which provides descriptive statistics for the variables used in the regressions. It confirms that the distribution of the dependent variables is highly skewed, with the median always at zero (one for the gatekeeper score) and the mean well above one; the 'max' column also indicates the presence of a few outliers for the broker and gatekeeper score.

The distributions of independent variables concerning productivity and the number of patents signed are also highly skewed, with some academic inventors producing no publications over the observed time span. The 74 academic inventors considered are predominantly senior ones, with a mean age of 55; over half of them being full professors, and less than a fifth assistant professors. With respect to the original distribution of academic inventors across disciplines (see Table 2), biology is slightly under-represented, in favour of Chemistry and Pharmaceuticals.

Table 6 reports the results of the regressions. Since the proposed brokerage measures can be considered as count data (number of instances of in-betweenness), and have a highly skewed distribution, we made use of negative binomial regressions (we also tested whether zero-inflated negative binomial regressions were more appropriate, but the Vuong test returned negative results; see Vuong, 1989). Note that the estimated coefficients cannot be directly interpreted as the marginal influence of the independent variable on the dependent one, as in OLS regression; instead, estimated coefficients indicate the change in the log of the expected counts for a unit change of the independent variable. Hence taking the exponential of the parameter estimate yields the percentage change in the expected count of brokerage scores.

Regressions have been run for all 74 academic inventors susceptible to brokerage measurement. We will comment first on the estimated coefficient of control variables and then explain how the number of patents (by type of ownership) affect the brokerage score, leaving a discussion of the effect of scientific productivity till last.

Age matters, but not much. It is not significant in regressions (3) and (4), and barely significant in regression (5). Regressions (1) and (2) indicate that being 1 year older increases an academic inventor's expected broker score by no more than 8 per cent. Rank dummies are not significant, except in one case (regression 4). Dummies for disciplines are either insignificant or significant at no more than 90 per cent.

Estimated coefficients for the number of patents, classified by ownership type, depend directly on the technical constraints of the proposed brokerage measures, but they are also quite informative about the nature of contacts established by academic inventors through their patenting activity.

We first observe that individual patents are not associated with high brokerage scores. On the contrary, having signed one's own patent diminishes the brokerage score by up to 55 per cent (regression (1)). This is because individual patents are very often signed by one or very few academic inventors, most of them colleagues at the same university, which explains why the negative effect is particularly severe for the broker measure (which requires the academic inventor to stand in between two industrial researchers).

University-owned patents do not seem to be associated with high broker scores, which again is a largely predictable result. University-owned patents are most often signed by colleagues in the same university, and occasionally by some students; at most, they can originate some brokerage position in between students. On the contrary, one extra university-owned patent increases the expected coordinator score by 464 per cent. The effect on the gatekeeper score is lower, because it is non-linear, that is, it depends on the total number of university-owned patents signed by the academic inventors, with a negative second derivative; moving from one patent to two, the score increases by 84 per cent; moving from two patents to three, we have an eight per cent decrease (however, academic professors with three university patents only, that is, with

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Table 5
Descriptive statistics.

Variables	Obs.	Mean	Median	Variance	Min	Max
Broker	74	4.81	0	210.2	0	109
Gatekeeper	74	7.30	1	386.5	0	131
Liaison	74	1.61	0	23.5	0	31
Coordinator	74	2.08	0	26.6	0	25
Age	74	55.5	56	78.4	38	74
Productivity	74	2.72	1.98	6.26	0	14.68
Late_productivity	74	3.81	2.88	13.8	0	20.38
Business-owned patents (no.)	74	4.64	3	30.0	0	28
University-owned pat. (no.)	74	0.78	0	1.10	0	4
Individual-owned pat. (no.)	74	0.35	0	1.57	0	7
Chemistry	74	0.28	–	–	0	1
Electronics & Telecom	74	0.24	–	–	0	1
Pharma	74	0.31	–	–	0	1
Biology	74	0.16	–	–	0	1
Full Prof.	74	0.59	–	–	0	1
Associate Prof.	74	0.26	–	–	0	1
Assistant Prof.	74	0.15	–	–	0	1

no additional business-owned patents, are very rare). However, the coefficients for university-owned patents in both regressions (3) and (4) are highly sensitive to the inclusion/exclusion of top gatekeepers and coordinators (we come back to this below).

Business-owned patents affect all our brokerage measures in a non-linear way. Adding one more of these patents to the portfolio of an academic inventor with one patent only, increases the broker score by either 82 or 90 per cent (depending on the regression: (1) or (2)), the gatekeeper score by 68 per cent, the coordinator score by 52 per cent, and the liaison score by 123 per cent. Even the academic inventor with the highest number of patents in our sample would see his brokerage score going up with one more patent: six per cent to eight per cent for the broker score, 27 per cent for the gatekeeper score, 15 per cent for the coordinator score, and 27 per cent for the liaison score.

While the relationship between business-owned patents and broker and liaison scores is pretty obvious (both these scores derive from the academic inventor standing in between two co-inventors, one of which needs to be an industrial researcher), it is less so for the gatekeeper score, and even less for the coordinator score.

Academic inventors may be gatekeepers when standing in between an academic colleague and either an industrial researcher

Table 6
Q7 Brokerage scores; negative binomial regressions over academic inventors' characteristics (standard errors in parentheses).

	Broker (1)	Broker (2)	Gatekeeper (3)	Coordinator (4)	Liaison (5)
Productivity	0.40***		0.36***	0.30**	0.23
	(0.13)		(0.13)	(0.13)	(0.26)
Late_productivity		0.21**			
		(0.09)			
Age	0.08**	0.07**	−0.01	−0.04	0.14*
	(0.03)	(0.04)	(0.03)	(0.04)	(0.08)
Business-owned patents (no.)	0.66***	0.68***	0.54***	0.44***	0.84***
	(0.11)	(0.11)	(0.11)	(0.12)	(0.26)
Business-own pat.^{2}	−0.02***	−0.02***	−0.01***	−0.01***	−.02***
	(0.004)	(0.00)	(0.00)	(0.00)	(0.01)
University-owned pat. (no.)	0.002	0.10	1.66***	1.73**	2.58*
	(0.72)	(0.73)	(0.63)	(0.68)	(1.40)
University-owned pat.^{2}	−0.02	−0.05	−0.35*	−0.29	−0.63
	(0.25)	(0.25)	(0.22)	(0.22)	(0.42)
Individual-owned pat. (no.)	−0.59**	−0.44*	−0.41*	−0.34	−0.32
	(0.29)	(0.27)	(0.24)	(0.24)	(0.50)
Chemistry	0.31	0.13	0.10	0.31	0.68
	(0.68)	(0.66)	(0.62)	(0.70)	(1.27)
Electronics & Telecom	0.95	0.63	−1.25*	−1.42*	1.59
	(0.77)	(0.75)	(0.71)	(0.79)	(1.44)
Pharma	−0.32	−0.52	−0.90	−0.64	−2.74*
	(0.65)	(0.63)	(0.61)	(0.69)	(1.67)
Associate Prof.	0.20	0.11	−0.32	−0.53	1.58
	(0.73)	(0.77)	(0.62)	(0.72)	(1.43)
Assistant Prof.	0.62	0.40	0.03	−1.77*	1.38
	(0.84)	(0.89)	(0.78)	(1.08)	(1.46)
Constant	−7.43***	−6.65**	−1.12	0.59	−13.74**
	(2.49)	(2.57)	(2.14)	(2.49)	(5.92)
	LR test of alpha = 0: $chi^2(01)$ = 352.78***	LR test of alpha = 0: $chi^2(01)$ = 363.14***	LR test of alpha = 0: $chi^2(01)$ = 412.3***	LR test of alpha = 0: $chi^2(01)$ = 103.3***	LR test of alpha = 0: $chi^2(01)$ = 139.0***
	No. of obs = 74	No. of obs = 74	No. of obs = 74	No. of obs = 74	No. of obs = 74
	log L = −126.6	log L = −128.8	log L = −158.2	log L = −97.5	log L = −76.0
	LR $chi^2(12)$ = 61.2	LR $chi^2(12)$ = 56.8	LR $chi^2(12)$ = 54.0	LR $chi^2(12)$ = 40.3	LR $chi^2(12)$ = 25.5
	Prob > chi^2 = 0.00	Prob > chi^2 = 0.00	Prob > chi^2 = 0.00	Prob > chi^2 = 0.00	Prob > chi^2 = 0.01
	Pseudo R^2 = 0.19	Pseudo R^2 = 0.18	Pseudo R^2 = 0.15	Pseudo R^2 = 0.17	Pseudo R^2 = 0.14

or a student. While university-owned patents grant some chances for the academic inventors to stand in between a colleague and a student, business-owned patents also provide the chance for standing in between a colleague and an industrial researcher; in addition, mixed teams (academic scientists and industrial researchers and/or students) are much more common with business-owned patents than with university-owned ones.

The existence of a positive effect of business-owned patents on the coordinator score is explained again by the high frequency of business-owned patents counting at least two academic co-inventors. If academic inventor *j* has worked on two business-owned patents, one with academic colleague *i* and another with colleague *z*, he will end up acting as a coordinator between the two even in the absence of any university-owned patent in his portfolio.

Fig. 3 may help in clarifying some of these technicalities, and also provides nice examples of top brokers, gatekeepers, and coordinators. It represents the ego-networks of selected academic inventors, who are represented by large black circles and labelled with a number, which is the code they have been given in the database; small circles are co-inventors and they are coloured according to their affiliation group; grey lines around subgraphs, each labelled with a different letter, indicate that the inventors/nodes inside the line are team members, that is they worked on the same patent(s).

Inventor *1622030* (centre-top of the figure) does not have an especially high score, but is representative of what we may call a 'pure' coordinator, that is an academic inventor who stands in between several of his colleagues, and has never worked with inventors from outside his affiliation group. He and the co-inventors circled by the 'A' line have worked on the same patent, as one can understand by noting every node is connected to all the others. This means that the coordinator score of inventor *1622030* does not derive from his collaboration with the other inventors of patent 'A', since they are connected to each other independently of him. In fact, inventor *1622030*'s coordinator score derives from his work on a different patent, which he has produced by working with the two inventors represented by the nodes on the right-hand side of his ego-network, outside the 'A' line. Inventor *1622030* acts as a coordinator between these two inventors, and those circled by A.

Similarly, all of the brokerage scores of inventor *224212* (bottom left corner of the figure) derive from his work on several different patents, such as those invented with co-inventors/nodes circled by the B, C and D lines (for the sake of tidiness, C and D have not been extended to include inventor *224212*, but the reader should be aware that he belongs to all teams). Note that patent B lists inventor *224212* as the only academic co-inventor, while C and D are more mixed (as much as the other patents, not represented by any circle line, which must have seen the participation of the co-inventors/nodes on the bottom right-hand side of *224212*'s ego-network). This heterogeneity explains why inventor *224212* records very high scores on all measures. A similar explanation applies to inventor *135223* (bottom right corner of the figure), even if this inventor's broker score is not particularly high, due to the limited number of industrial researchers in his ego-network.[15]

Finally, we note that inventor *1102820* (centre of the figure) has zero liaison score, because the ego-network does not include any student, and also zero coordinator score, because the only two academic co-inventors in the ego-network are linked by a direct tie. A similar explanation applies to the relatively low liaison and coordinator scores of inventor 521985 (top left corner of the figure), whose ego-network includes only two students and three academic co-inventors, two of which are linked by a direct tie.

Going back to the regressions in Table 6, we note that from all of them with the exception of number (5), academic inventors with strong brokerage positions emerge as highly productive scientists, both when their overall publication record is considered and when the attention is restricted only to their recent years of activity.[16] Regression (1), for example, tells us that one more paper per year by the academic inventor increases his expected broker score by 49 per cent (from regression (2) we see that a similar increase in late-productivity produces a 23 per cent increase).

These results cannot be explained by the positive association between scientific productivity and number of patents (found by the studies we reviewed in Section 2), since in all the regressions we control by the latter. Rather, it is suggestive of the possibility that highly productive scientists have, *ceteris paribus*, a more diverse set of collaborations, which includes actors from different affiliation groups, several of whom are connected only through the co-inventing activity performed along with the productive scientists themselves. This is confirmed by looking at the biographies of the top brokers and gatekeepers from our sample, which we report in Appendix B.

It is important to remark that regressions in Table 6 are based on a small sample, and one in which (by moving from all respondents to our questionnaire to only those with more than one patent) outliers may have a greater weight (see footnote 14 and Appendix A). In order to check the robustness of the results we have re-run the regressions of Table 6 by excluding outliers (defined as observations with values of the dependent variable in the 95th percentile – they are always 4 observations). In regressions (1) and (2) the coefficients for productivity and age are somehow weakened, but still highly significant; coefficients for business-owned patents and their quadratic term never change much; and two dummies for disciplinary affiliation (Chemistry and Electronics) turn out significant and positive (which makes some sense, since these are the fields where more mixed university–industry teams are found). In regressions (3) and (4) the estimated coefficients for both university-owned patents and their quadratic term become insignificant. In regression (4) also productivity becomes non-significant. These findings confirm that the association between scientific productivity and the academic inventors' position in the inventors' network is stronger for brokers and gatekeepers, that is, those figures that are in between different inventors from industry, or in between the latter and other academic inventors. They also suggest, not surprisingly, that in order to achieve such positions academic inventors have to be found responsible for business-owned patents, rather than university-owned ones.

4.2. Brokerage positions and the strength of ties

Brokerage scores calculated so far amount to structural properties of the network of inventors, and of nodes therein. They do not tell us anything on the quantity and quality of information or other resources which academic inventors may pass on or receive from co-inventors.

In this section we report the results of three questions asked to academic inventors about their relationship with co-inventors after the patent was applied for. In the first question it was asked whether the academic inventor and the co-inventor had worked together on any research project after the patent (the question was asked separately for each co-inventor). In the case of a negative answer, a second question was asked about whether the inventor foresaw any chance of future research cooperation with the co-

[15] The ego-networks of inventors 224212 and 135223 share a common co-inventor/node, which explains the line linking them.

[16] We report the results of the regression including 'late-productivity' instead of 'productivity' only for the case with the broker score as the dependent variable. Results with different dependent variables are pretty much the same.

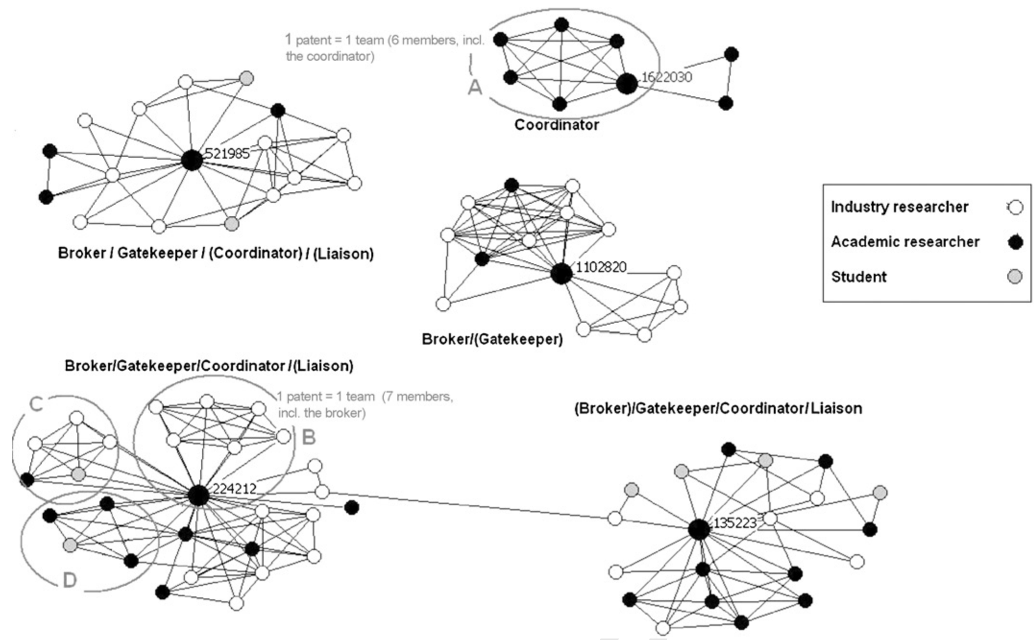

Fig. 3. Top brokers, gatekeepers and coordinators.

Table 7a
After-patent research cooperation and contacts, by affiliation group of the co-inventor (% of co-inventors).

Co-inventor's affiliation	Research cooperation[a]	Contacts and info. exchanges[a]
Academic	44% (149)	79% (141)
Industrial	25% (164)	46% (160)
Student	29% (24)	63% (24)

[a] No. of valid answers in parentheses.

inventor. In the case of a further negative answer it was asked whether the inventor and the co-inventor were at least still in touch, for occasional exchanges of information.[17]

Here we summarize answers to the first two questions in a 'cooperation' variable, which takes value one in the case of a positive answer to at least one of the two questions, and zero otherwise. Another variable, 'contacts', takes value one in the case of a positive answer to at least one of the three questions, and zero otherwise.

Table 7a shows that instances of after-patent cooperation are much more frequent when the co-inventor is an academic, rather than an industrial researcher or a student: academic inventors have engaged or plan to engage in further joint research efforts with almost one out of two academic co-inventors, but only with one out of four industrial ones (and a bit less than one out of three students).[18]

As one might expect, academic inventors are still in touch with the vast majority (79 per cent) of their academic co-inventors. They are also in touch with the majority of their (former, at the time of submitting the questionnaire) students (63 per cent), and a much lower percentage of industrial researchers (46 per cent). From Table 7b, we note that significant differences also exist across disciplines: academic inventors in Biology and Electronics & Telecoms are much more likely than those from other disciplines to entertain future research relationships and/or to keep in touch with their co-inventors; the difference holds across all types of co-inventors. The only notable exception to this pattern is found in Pharma, where academic inventors report lower scores than those from Biology and Electronics & Telecoms when it comes to future research cooperation with academic colleagues, but higher scores for future contacts. We do not have a ready interpretation for these results: the number of valid answers upon which they are based suggests they may depend on the personality of respondents across disciplines, rather than discipline-specific factors.

A research question of immediate interest is the following: are academic inventors with high brokerage scores any better, or just more interested, at keeping in touch with their co-inventors? A positive answer would suggest that academic inventors may be pursuing any of the various brokerage positions in order to manage actively and take advantage of them, or at least that they take advantage of it once they reach it. The type of advantage differs with the contents of the relationship, whether this implies some joint research or just access to information (which in turn may be

Table 7b
After-patent research cooperation and contacts, by discipline and affiliation group of the co-inventor (% of co-inventors).

	Chemistry	Pharmaceuticals	Biology	Electronics & Telecom
Research cooperation[a]				
Academic	31% (48)	25% (51)	71% (24)	77% (26)
Industrial	11% (53)	4% (55)	62% (21)	57% (35)
Student	29% (7)	0% (10)	100% (3)	50% (4)
Contacts and info. exchanges[a]				
Academic	55% (42)	96% (49)	88% (24)	81% (26)
Industrial	27% (49)	29% (55)	86% (21)	74% (35)
Student	57% (7)	60% (10)	100% (3)	50% (4)

[a] No. of valid answers in parentheses.

[17] More precisely, the three questions were: (i) "After filing the patent, have you and the co-inventor collaborated on any other research project, either leading or not leading to another patent?"; (ii) Do you plan to collaborate again with the co-inventor on projects involving invention, innovation or research (excluding the mere organization of conferences, seminars etc.)?; (iii) (If the answer to ii. was 'no') "Do you still have any opportunity to meet the co-inventor and exchange technical, scientific or professional opinions?"

[18] The number of co-inventors for which valid answers were obtained is very low compared to the number of co-inventors whose affiliation could be retrieved. This is due to the questionnaire being rather long, which caused many interviewees (especially those with many co-inventors) to decline answering all the questions.

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Table 8a
After-patent research cooperation; logit regressions over brokerage scores and co-inventors' characteristics (standard errors in parentheses).

	All co-inventors (1)	All co-inventors (2)	Academic co-inventors only (3)	Industrial co-inventors only (4)
Productivity	0.07	0.02	−0.02	−0.25
	(0.06)	(0.07)	(0.09)	(0.18)
No. of patents	−0.31***	−0.44***	−0.62***	−0.07
	(0.10)	(0.13)	(0.19)	(0.06)
(No. of patents)^2	0.01**	0.01**	0.01**	–
	(0.00)	(0.00)	(0.01)	
Age	0.01	−0.01	−0.01	−0.01
	(0.02)	(0.03)	(0.04)	(0.05)
Associate Prof.	−0.80	−1.39**	−1.94**	−0.63
	(0.52)	(0.61)	(0.81)	(1.19)
Assistant Prof.	−0.80	−1.38*	−2.56**	−0.77
	(0.63)	(0.71)	(1.05)	(1.24)
Chemistry	−1.86	−2.41***	−1.53**	−5.40***
	(0.44)	(0.54)	(0.65)	(1.68)
Electronics & Telecom	1.10*	0.73	1.68*	−2.35
	(0.57)	(0.70)	(0.98)	(1.67)
Pharma	−2.24***	−3.09***	−2.24***	−6.46***
	(0.48)	(0.64)	(0.80)	(1.84)
Broker	–	−0.03	−0.05*	−0.12**
		(0.02)	(0.03)	(0.05)
Gatekeeper	–	0.06**	0.09**	0.14**
		(0.03)	(0.04)	(0.07)
Coordinator	–	−0.13**	−0.13*	−0.37**
		(0.06)	(0.07)	(0.15)
Industrial	−1.25***	−1.31***	–	–
	(0.32)	(0.35)		
Student	−0.73	−0.90	–	–
	(0.58)	(0.58)		
Constant	1.62	4.46**	4.54	5.63
	(1.66)	(2.08)	(2.97)	(4.07)
Obs	337	337	149	164
log *L*	−152.0	−147.6	−72.9	−56.8
LR chi^2	125.87***	134.68***	58.41***	70.82***
Psuedo R^2	0.29	0.31	0.29	0.38

useful to access resources such as data, references, useful contacts or sources of funding).

Table 8a reports the results of a logit regression, where the dependent variable is the probability that a pair (academic inventor, co-inventor) have further cooperated or plan to cooperate on research of some kind, according to the academic inventor's answer to our questionnaire. Specification (1) includes as regressors the academic inventor's scientific productivity, number of patents, and age (quadratic terms are inserted if significant), as well as dummies for the academic inventor's rank and disciplinary affiliation (full professor and biology as reference cases, respectively) and for the co-inventor type (industrial researcher or student, with academics as the reference case).

Specification (2) adds to the model the academic inventor's brokerage, gatekeeping and coordination scores (liaison scores cannot be included, due to multicollinearity problems). Specifications (3) and (4) estimate separate models for academic and industrial co-inventors. No separate model can be estimated for relationships with students, due to the small number of the latter.[19]

In all specifications except (4) the number of patents signed by the academic inventor negatively and significantly affects the probability of the latter collaborating further on research with the co-inventor; the quadratic term is not robust to the exclusion of outliers, while the linear term holds always as significant. On the contrary, the academic inventor's age and scientific productivity do not appear to be relevant. Obvious explanations for this result are that academic inventors with many patents face increasing opportunity costs for maintaining strong ties with all co-inventors than with their colleagues with fewer patents.

The academic inventor's rank affects the probability of research cooperation, with associate and assistant professors less likely than full professor to further cooperate with co-inventors, especially academic ones. The coefficients for the relevant dummies are always negative; they are also significant in specifications (2) and (3), the latter being specific for relationships with academics, but not in specifications (1) and (4), the latter being specific for relationships with co-inventors from industry. This suggests that academic rank affects relationships with colleagues, but not with industrial researchers.

Regarding the latter, both specifications (1) and (2) suggest that academic inventors are less likely to maintain research links with them, as opposed to academics and students (the coefficient for students is negative but not significant). This result holds regardless of the academic inventor's rank and number of patents.

Specifications from (2) to (4) indicate consistently that high brokerage and coordination scores negatively affect the probability of further research cooperation with both academic and industrial co-inventors; on the contrary, higher gatekeeping scores increase such a probability. This is tantamount to saying that academic inventors who are central in one of the two groups of co-inventors (brokers being in between industrial researchers, coordinators being in between other academics), but do not stand in between the groups (as gatekeepers do), entertain weaker relationships with their co-inventors. One ready explanation for the different result on brokerage vs. gatekeeping scores is that pure brokers (academic inventors with a high brokerage score and a low gatekeeping

[19] Testing for interaction between the type of co-inventor and the other regressors through separate regressions for each type was preferred for introducing interactions directly into general specifications such as (1) and (2), because of the difficulties of interpreting marginal effects in logit regressions with many interaction terms.

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Table 8b
After-patent contacts and information exchanges; logit regressions over brokerage scores and co-inventors' characteristics (standard errors in parentheses).

	All co-inventors (1)	All co-inventors (2)	Academic co-inventors only (3)	Industrial co-inventors only (4)
Productivity	0.31***	0.23**	0.47*	0.16
	(0.08)	(0.09)	(0.26)	(0.12)
No. of patents	−0.01	0.00	−0.17**	0.48**
	(0.02)	(0.04)	(0.09)	(0.20)
(No. of patents)^2	–	–	–	−0.01**
				(0.01)
Age	0.04	0.02	0.09	0.04
	(0.02)	(0.03)	(0.07)	(0.04)
Associate Prof.	1.02*	0.38	−0.72	2.13**
	(0.53)	(0.58)	(0.99)	(0.97)
Assistant Prof.	0.34	−0.57	−1.06	0.24
	(0.58)	(0.66)	(1.13)	(1.00)
Chemistry	−1.93***	−3.18***	−1.25	−6.14***
	(0.54)	(0.73)	(0.81)	(1.71)
Electronics & Telecom	0.62	−1.01	1.30	−3.81***
	(0.67)	(0.87)	(1.15)	(1.69)
Pharma	−0.86	−2.38***	1.88	−6.15***
	(0.53)	(0.77)	(1.25)	(1.68)
Broker	–	−0.07***	−0.04	−0.13***
		(0.02)	(0.04)	(0.04)
Gatekeeper	–	0.08***	0.05	0.15***
		(0.03)	(0.05)	(0.05)
Coordinator	–	−0.22***	−0.15	−0.47***
		(0.06)	(0.11)	(0.15)
Industrial	−1.76***	−1.91***	–	–
	(0.31)	(0.33)		
Student	−1.00*	−1.35**	–	–
	(0.53)	(0.56)		
Constant	−0.71	2.34	−2.95	0.65
	(1.60)	(2.11)	(4.60)	(3.09)
Obs	325	325	141	160
log *L*	−166.1	−157.6	−44.6	−74.6
LR chi^2	100.86***	117.97***	54.01***	71.31***
Psuedo R^2	0.2329	0.2724	0.3769	0.3233

score) may in fact be consultants, whose patents stem from several short-lived collaborations with industry. On the contrary, gatekeepers whose ties with industry arise along those with the rest of academia via public-private ventures and consortia, maintain more stable relationships with all co-inventors.[20] We have a less ready explanation for coefficients of the coordinator score, especially for relationships with academic co-inventors. We note however that, in general, coordination scores are much lower than brokerage and gatekeeping scores, which possibly indicates that academic inventors with high coordination and low gatekeeping scores (that is, pure coordinators) have fewer patents, which in turn arise from more occasional projects.

It is important to note, however, that top brokers and top gatekeepers tend to coincide, to the extent that almost all academic inventors who score very high on one measure do the same for the others. With one exception (see Appendix B), trade-offs appear therefore to be relevant for academic inventors with lower scores.

Finally, we note that discipline dummies are very important, in the direction already suggested by Table 7. A calculation of marginal effects, based upon the coefficients estimated in model (2), suggests that such effects are the strongest: a median academic inventor from Chemistry or Pharmaceutics has from 50 to 64 per cent less probability of maintaining research ties with co-inventors than a similar academic inventor from Biology or Electronics & Telecommunications. Marginal effects for assistant and associate professors, compared to full professors, are around −22 per cent, which is also the marginal effect for co-inventors being industrial ones.

Table 8b reports the results of four regression exercises parallel to those in Table 8a, but withreference to looser contacts, such as those for mere information exchanges. Here we note a different impact for scientific productivity and number of patents. The former has a significant coefficient in all specifications except (4), the latter on the contrary appears significant only in this specification. This suggests that highly productive academic inventors tend to maintain contacts with more co-inventors than less productive ones, but this holds for academic co-inventors and not for industrial ones. At the same time, having many patents is associated with keeping in touch with many more co-inventors from industry, but not from university (in specification (3) the sign of the coefficient for the number of patents is indeed negative and significant); however, such contacts are not for research, but for more generic exchanges of information.[21]

The effect of academic rank on the probability of maintaining contacts with co-inventors is less marked than in regressions on research cooperation: full professors do not appear to behave differently from assistant professors, while associate professors seem more likely to maintain contacts than colleagues from both the other ranks, but the effect is significant only in specifications (2) and (4). Effects of disciplines are significant in all models except (3), which suggests they mainly refer to relationships with industrial co-inventors (that is, the probability of maintaining contacts with academic co-inventors does not vary across disciplines).

[20] For a summary description of this type of ventures and consortia, see the biographical notes on top brokers and gatekeepers in Appendix B.

[21] Specifications (3) and (4) differ for the presence of a quadratic term for the number of patents, which was inserted only in specification (4) because it was significant and robust to checking for outliers.

Coefficients in models (1) and (2) suggest that contacts and information exchanges, like research cooperation ties, are maintained with different probabilities according to the type of co-inventors. In this case, contacts with both industrial and student co-inventors are less likely to be maintained than those with academics. Marginal effects, as derived for median academic inventors from model (2), appear however not to be great, ranging between eight and two per cent.

The impact of brokerage, gatekeeping, and coordination scores differ across types of co-inventors. In specifications (2), which refers to all co-inventors, and (4), which refers only to co-inventors from industry, all coefficients are significant. They also bear the same signs as in Table 8a, that is, the various in-between positions are related to the probability of maintaining contacts in the same way they are related to the probability of maintaining research ties, as long as industrial co-inventors are involved. However, contacts with university co-inventors are maintained regardless of the network position of the academic inventor. Overall, this suggests that gatekeepers, as opposed to pure brokers or coordinators, do a better job of keeping in touch with industry, while relationships within the academy do not depend on the scientist's position within the network of inventors.

5. Conclusions

In this paper we have adapted a set of brokerage and gatekeeping measures proposed by Gould and Fernandez (1989) that may be of help in clarifying the relationship between academic inventors and their co-inventors, whether from industry or from academic or student bodies.

We find out that strong brokerage positions are very few, and they are held by scientists with both a large number of patents, a strong publication record, and (in a few instances) an older age. We also find that academic inventors' relationships with their co-inventors vary in strength and content, according to the former's position within the network of inventors, and to the latter's affiliation. In particular, relationships with co-inventors from industry are less likely to be maintained over time than those with co-inventors from academia; they are also less likely to go beyond contacts for information exchanges and involve further research collaborations. Moreover, academic inventors whose network position is similar either to that of a consultant (pure broker between otherwise unconnected industrial co-inventors) or an 'ivory tower' scientist (pure coordinator of other academic co-inventors) are less likely to maintain any type of relationship other than gatekeepers (who stand in between industrial and academic co-inventors). However, with a few exceptions, top brokers also tend to be top gatekeepers, so the results mainly apply to academic inventors with high, but not the highest scores.

These results also suggest that previous findings on the centrality of academics in networks of inventors (as reviewed in Section 2) have different explanations and implications. Some central positions may be explained by academic inventors sitting in between homogeneous groups of co-inventors (all of them either from industry or academia) while a few others span the boundaries of the two realms and, quite interestingly, appear to maintain stronger ties with both.

The joint reading of our quantitative evidence and the top brokers' biographical notes in Appendix B suggests that top brokers and gatekeepers manage actively their relationships outside university. Some of them, especially those who have signed patents only for one or two different assignees, are likely to keep in touch mainly for research or research funding purposes. Others, such as those academic inventors with many different assignees and/or many assignees such as public consortia and the like, may nurture their personal links outside universities for more strategic purposes. The existing literature on university patenting has focused almost exclusively on academic inventors' monetary incentives (Lach and Shankerman, 2003; see also Stern, 2004, for a more general treatment). Here we find that the social contacts gained through collaboration with industry may be part of the reward, as they help to boost the academic inventor's reputation and career both inside and outside the university.

Future research will have to test this hypothesis further through the collection of longitudinal data on academic scientists' careers, and more detailed questionnaire data on the exact contents of the information exchanges between academic inventors and their co-inventors, both during and after their collaboration on the patent. Longitudinal data will help to test whether social contacts with industrial co-inventors do help academic inventors throughout their careers, while refined questionnaire data will also help to build directed graphs, thus allowing more precise applications of the brokerage concepts and scores.

A related research line will possibly investigate benefits enjoyed by the students of academic inventors with high brokerage scores. Data from the same database used for this paper have already been exploited to find out whether Masters students, supervised by academic inventors, have easier access to the labour market with positive results (Zinovyeva and Sylos-Labini, 2007). The inclusion of brokerage scores and extending the research to other countries will help in confirming the general validity of this result.

Appendix A.

See Table A1.

Appendix B. A biographical sketch of top brokers and gatekeepers

In this Appendix we briefly report some significant biographical information on the top brokers and gatekeepers in our sample, which we retrieved using standard search engines on the World Wide Web, and validated through brief e-mail exchanges with the scientists themselves.

Only six academic inventors have a brokerage score higher than 10. All of them are senior full professors, born between 1935 and 1956. For two of them, M.B. and F.P., who scored respectively 109 (top score) and 33, we were unable to find much biographical information, apart from a short CV listing affiliation (University of Rome, "La Sapienza", the largest university in Italy, and the University of Modena and Reggio, respectively) and discipline (Pharmaceutical Chemistry and Materials Technology, respectively). M.B.'s 15 patents belong to six different assignees, one of which is a large public research organization, while the others are medium-sized Italian pharmaceutical companies. Three out of F.P.'s 13 patents are assigned to General Electrics, and all but one of the others to companies within the ENI group.

The most junior of the remaining four academic inventors with a high brokerage score is G.P., a professor of Electronics at the University of Catania (Sicily), which he represents within *Plast_Ics*, an academic consortium supported both by the Ministry for University and Research and by STMicroelectronics, an Italian company with the highest number of academic patents. The consortium lies at the core of the most important hi-tech district of Southern Italy, the so-called 'Etna Valley', the origin of which dates back to a decision by STMicroelectronics to locate some of its R&D facilities in Catania (Santangelo, 2004). G.P.'s patents in our database number eight; three are for STMicroelectronics, and the remaining ones for Italtel, once the manufacturing arm of Telecom Italia (when the latter held the monopoly over Italian telephone services), and

Table A1
Percentage distribution of all academic inventors in the sample vs. questionnaire respondents, by year of birth, discipline, and no. of patents.

	All academic inventors	Respondents	Respondents with no. patents >1
Year of birth			
<1941	26.0	18.6	23.0
1942–1949	23.7	23.1	35.1
1950–1958	26.6	30.1	29.7
>1958	23.7	28.2	12.2
	100.0	100.0	100.0
Discipline			
Pharma	26.3	31.4	31.1
Biology	26.0	26.9	16.2
Chemistry	24.7	23.7	28.4
Electronics & Telecom	23.0	17.9	24.3
	100.0	100.0	100.0
No. of patents			
1	63.8	65.4	-
2–5	29.6	26.3	75.9
>5	6.6	8.3	24.1
	100.0	100.0	100.0
Productivity[a]			
0	0.7	0.5	1.4
(0–1]	21.1	17.3	21.6
(1–2]	33.1	30.8	28.4
(2–5]	38.5	42.2	33.8
>5	6.7	9.2	14.9
	100.0	100.0	100.0
Productivity[a] (statistics)			
Min	0	0	0
Max	14.68	14.68	14.68
Mean	2.24	2.46	2.72
Median	1.88	2.05	1.98
SD	1.70	1.90	2.50

[a] No. of publications per year.

now a service company jointly shared by Telecom Italia and Cisco Systems.

STMicroelectronics also plays an important role in explaining the high brokerage score of R.Ca., a professor of Electronics at the University of Pavia. All 28 patents in the database signed by R.Ca. belong to STMicroelectronics. In particular, R.Ca. is the founder of Microlab, a joint initiative of his university and STMicroelectronics that also signed contracts with Conexant Systems, Lucent Technologies and National Semiconductors, among others. More recently, R.Ca. played a key role in the decision of Marvell Semiconductor, a US multinational, to open an R&D centre in Pavia, and to locate its Italian headquarters there.

P.C., who heads the Pharmacy Department at the University of Parma, has also been the promoter of a university consortium, Tefarco_Innova, for the production of innovative pharmaceutical technologies. Before this, P.C. signed a number of patents for several pharmaceutical companies (10 different assignees for 24 patents).

Finally, R.Co. is the academic 'broker' with the longest experience in foreign universities, first in Cambridge, then in Heidelberg. A molecular biologist, he returned as full professor at his *alma mater*, the University of Naples, in 1980. In 1990 he also became head of IRBM-Angeletti, a laboratory staffed with over 150 researchers under the control of the pharmaceutical multinational Merck, located in Rome. Most recently (December 2007), he was short-listed for the presidency of CNR (Centro Nazionale delle Ricerche), the largest public research organization in Italy. All of his six patents in our database are assigned to IRBM-Angeletti. He is the founder of an academic spin-off presently hosted within the premises of a consortium of private and public institutions in Naples.

With the exception of R.Co., all the academic inventors with a brokerage score over 10 also have a comparable gatekeeper score. Among those who have a very high gatekeeper score but <10 broker score, five have a gatekeeper score over 10. The top gatekeeper scorer in this group is L.N., a chemical engineer from the University of Naples with a long record as promoter of public and joint public-private research consortia. L.N. ultimately started quite a remarkable political career, which culminated in his appointment as Minister for Reform and Innovation in the Public Administration, from 2006 to 2008. Almost all of his 10 patents have different assignees, one which is L.N. himself (three are assigned to as many individual inventors, one to the Ministry of University and Research, one to the University of Brighton in the UK, and the remaining to Italian and foreign multinationals).

Another academic 'gatekeeper' of some relevance is M.M., who is currently deputy Rector of the University of Urbino and was until recently the president of CIB, the Inter-University Consortium for Biotechnologies, to which 25 Italian universities are affiliated. He is also the assignee of one of his three patents in the database, alongside with his co-inventors; the other two belong to the European Union and to a local company, respectively.

Finally, G.G. also deserves some mention. He is full professor of Telecommunications at the Tor Vergata University of Rome and a leading expert in radar technology, having represented Italy at a number of international organizations involved in air traffic control, such as ICAO (the International Civil Aviation Organization) and Eurocontrol (European Organization for the Safety of Air Navigation). Four out of his 11 patents are assigned to his university, all but one of the others to Selenia, now Selex S.I., a manufacturer of professional electronic systems and part of the Finmeccanica group.

These short biographical notes suggest that high brokerage and gatekeeping scores are not necessarily associated with patent-measured in-between positions across companies, but only to in-between positions across co-inventors: several of our 'brokers' have patented just for one or two assignees, although they have worked with many of the assignees' employees. All brokers and gatekeepers, however, appear also to have consulted for or cooperated with a variety of assignees, from both the business sector and public research organizations, or public–private consortia. This suggests that the networks in which our academic brokers and gatekeepers are involved result from entrepreneurial initiatives such as setting up a mixed university–industry lab, or a consortium. Initiatives of this kind require extensive negotiations about resources and exchanges of financial or administrative information. The social ties created in this way may be shorter-lived than those with fellow researchers within academia, the former being merely instrumental to some practical goals, the latter consisting of research partnerships between owners of complementary skills and knowledge assets. This interpretation is consistent with the results of the econometric exercise in Section 4.2

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