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WHAT HAVE WE LEARNED BY APPLYING SOCIAL NETWORK ANALYSIS TO THE STUDY OF UNIVERSITY INDUSTRY RELATIONS?

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ABSTRACT

The aim of this work is to give an overview on the development of theoretical concepts and methodological approaches to investigate innovation networks, in particular the use of social network analysis in the study of university industry relations. The structure of networks can be analysed through the lens of Social Network Analysis. This methodological approach is described and its fundamental concepts are presented. The paper then reviews the applications of this approach on the study of university industry relations. These relations can be considered as an innovation network, in the sense that the interactions established by its participants have more or less defined innovation goals. Different structures in the relations may result in different innovation outcomes, and the use of SNA may be particularly useful to understand differential outcomes. It is thus important to take stock of the knowledge concerning the efforts that have been made to probe the complex phenomena of university industry relations and, in particular, how approaches based on social network analysis have been used to understand it. This work is based on a review of available literature on the topics. The paper aims at systematizing the information and knowledge related to the application of SNA on university industry networks, highlighting the main research pathways, the main conclusions and pointing possible future research questions.

INTRODUCTION

Social network analysis can bring many benefits for the study of the relations between the university and the industry. Relations between university and industry can be considered as an innovation network, in the sense that the interactions established by its participants have more or less defined innovation goals (Mansfield and Lee 1996). Social network analysis is the study of social structure (Wellman and Berkowitz 1988). Social network analysis describes a group of quantitative methods for analyzing the ties among social entities and their implications (Wasserman and Faust 2007). An important aspect in social network analysis is to identify key players in a network (Borgatti 2003). Social network analysis allows calculating measures and drawing graphs that describe and illustrate the individual and collective structure of a network.
The main measures calculated in SNA are cohesion measures, centrality measures and subgroup measures. Cohesion describes the interconnectedness of actors in a network (Hawe et al. 2004). The main measure of cohesion is the density of the network, which corresponds to the total number of ties divided by the total possible number of ties. Centrality measures identify the most prominent actors, i.e. those extensively involved in relationships with other network members (Freeman 1979). The subgroup measures show how a network can be partitioned in more or less independent subsets.
With the use of social network analysis it is possible to understand the different innovation outcomes in university industry relations by analyzing the different SNA measures and the structure of the social network. SNA can be conducted to find the key elements in the network that exhibit a wide range of connections strength. The key elements can influence the network structure and they play a significant role for affecting the innovation networks developed between university and industry (D'Este and Patel 2007). This paper makes a review of the literature that has used social network analysis to study university industry relations. The paper aims at systematizing the information and knowledge related to the application of SNA on university industry networks, highlighting the main research approaches, the main conclusions and pointing possible future research questions. The following section presents the research methodology. Sections 3 and 4 are the core of the article, where the results of the literature review are presented.

METHODOLOGY

The most important databases on scientific literature were accessed and searched using a combination of relevant search strings. The accessed databases were Web of Science, Scopus, JSTOR, Emerald, IEEE, ABI/INFORM, EconLit, Academic Search, NBER, and others. A selection of approximately 150 papers was retrieved based on relevance, quality, non-redundancy and impact criteria. A set of approximately 30 papers was selected to write this review, based on the same criteria and on subjective appreciations of their contributions to knowledge and to the academic debate.

MOST COMMON NETWORK ANALYSIS CONCEPTS USED IN STUDIES OF UNIVERSITY-INDUSTRY RELATIONS

Social network analysis use concepts that are related to the structural properties of the network and indicators that are related to relational properties of the network. The most used social network analysis concepts related to structural properties of the network in studies on university-industry relations are the concepts of density, component, and subgroups. The most used social network analysis concepts related to relational properties of the network are the concepts of degree, geodesic distance, centrality and betweenness centrality.
The concepts related to structural properties of the network are basic and important concepts that characterize the overall structure of the network, namely in terms of its global cohesion (trough the concept of density), in terms of its internal structure concerning the existence of large groups inside the network (through the concept of component) and in terms of smaller, cohesive and more specifically defined subgroups (also through the concept of component and, more rarely, through the concept of clique). The combination of these three indicators and an adequate interpretation of their meaning provides useful descriptions and characterizations of the network, in terms of the position of their nodes and constituents. The characterization is frequently complemented with visual aids, namely through sociograms. The sociograms by themselves are very useful in the overall characterization process of the network. Several studies use exclusively the sociograms to analyse the structure of the network, without performing, or at least presenting, a formal numerical analysis using the formal concepts of social network analysis.
The concepts related to relational properties of the network are often at the centre of the analytic procedure, and are used in several ways according to specific research objectives. The concepts of degree and centrality is used to detect to what extent actors are connected to other actors, and that of betweenness centrality is used to characterize the intermediary position of the actors in the network. Besides the main concepts referred above, other concepts related to these ones are also used, but less often. These include the directional variants of degree centrality, the concepts of in-degree or out-degree, other centrality measures such as the closeness centrality, the eigenvector centrality (which is an indicator of closeness centrality that minimizes local conditions), and the concepts of direct ties, indirect ties and valued ties. These more specific and detailed concepts/indicators are rarer in the literature that analyses university-industry relations.

MAIN THEMATIC APPROACHES

There is not a great number of articles that addresses specifically the problem of university–industry relations using SNA techniques. There is a variety of perspectives that reflect specific and idiosyncratic concerns of the authors. Apparently there are few papers that follow the same guidelines or share identical perspectives. However, there are small groups of authors that build on past works or use identical databases, such as patent databases.
The articles were classified in three main themes, in terms of the main study object or main research preoccupation or framework: 1) the study of the characteristics of personnel/institutional networks that are prominent in university-industry relations; these studies generally rely on the use of patents that are co-produced jointly by university and non-university members, and the patterns of collaboration are analysed; 2) the study of university-industry relations in the context of specific industrial settings or in the context of specific institutional conditions; these studies may rely also on patent databases but other types of data may be used, either primary data, obtained through questionnaires, or secondary data, obtained through diverse documental sources; 3) the contribution of the study of university-industry relations to the validation of theories; these studies also rely on a mix of patent, primary and secondary data.
In addition to these themes there are other themes that are addressed in these studies, either in a parallel way or as a theme that frames the former or the research approach. These may include the search for an optimal structure for innovation production and diffusion, the validation of theories, the consideration of structural properties of networks as independent or dependent variables, the use of different methodological perspectives and data sets or just the description of a certain phenomenon or process.
The combination of these themes and subthemes increases the content variety of the set of papers that were reviewed. As a consequence, and as stated above, the themes that could be common to the papers are, in broad terms, the three main themes above indicated, but, within each one, the approach and main research concerns and targets are quite different. As such, the literature will be analysed not only through the lens of the broad themes, but also through the details of the specific papers. This methodology will permit to extract from the papers the main academic debates and to highlight the respective contributions to knowledge. The next sections will perform that task. Table 1 synthesises the results.

CHARACTERISTICS OF PERSONNEL/INSTITUTIONAL UNIVERSITY-INDUSTRY NETWORKS

Databases on scientific literature have been extensively used to analyse the patterns of collaboration between scientists. Patent databases are also being explored to analyse the patterns of collaboration between academia and industry.

The impact on fundamental research of an orientation to patenting and commercialization has been researched trough the relationship between patenting activity and publication record of university researchers, and in general the results point to a positive correlation between patenting and publication activity (Czarnitzki et al. 2009). This theme is revived with a social network approach (Balconi and Laboranti 2006) and the results support the positive relationship between publication record and patenting activity. The author argues, in line with other similar arguments (Rosenberg and Nelson 1994), that industry feeds on academic research but that academic research also needs inputs from high technology industries in order to find direction to its research. So, academics that are close and collaborate with industry producing patents are also the ones that are more productive in purely scientific terms.

An exploratory analysis of the simultaneous embeddedness of researchers in scientific and technological networks (Breschi and Catalini 2010), which compares networks of authors, inventors and authors-inventors, and the overlap between them, argues that author-inventors play a crucial role in connecting the other two networks (only authors and only inventors) and occupy important positions in each community, in spite of the fact that maintaining a central position in one community comes at the expense of being able to occupy a similar position in the other community. The role of academics as fundamental intermediaries between public and private research is explored in a study (Lissoni 2010) that founds that academic inventors tend to be more central actors in broker and gatekeeping positions, although strong brokerage positions are very few and held by scientist with many patents and publications. De Stefano and Zaccarin (2013) reach similar conclusions regarding the larger relational activity of academic authors-inventors vis-a-vis industrial authors-inventors.

Two important differences were also apparent in Balconi et al. (2004): academic inventors were more connected than non-academic inventors (higher degree values), and had a more central position (higher values of betweenness). The central position of academics or of the university is a characteristic that often shows up in analysis of networks where public research organisations are involved (Owen-Smith and Powell 2004, Balconi and Laboranti 2006, Breschi and Catalini 2010, Protogerou et al. 2013).

The main objective of Leydesdorff' study (Leydesdorff 2004) is to reveal the knowledge base of patents and to see how much innovation is really based on science. This question is important because theories about university-industry relations are historically influenced by the biotechnology sector. The biotechnology sector is a science-based one whose inventive activities tend to be performed in close collaboration with public research organizations and whose output is patented through co-authorships or co-assignments between academic and industrial inventors. The access to and the analysis of patents databases have become easier and many studies have thus relied on these data to infer general conclusions to other fields of science, that are not so formalized as the biotechnology sector in terms of literature relations. The study analysis two sets of patents, extracted from the USPTO, one based on patents that have a university as a co-assignee, and another that has a Dutch address as an assignee. The structure of the co-words networks linking patents and their citations to other patents and scientific literature is analysed. The analysis is entirely based on the visualization of sociograms, with nodes as (co)words. The two networks are quite different. In the set of university patents (which represents university-industry relations) the fields of biotechnology and molecular biology dominate the set and the knowledge base of the patents, and the visualisation shows a neat organization around the intellectual organization of the disciplines. In the set of Dutch patents (representing the knowledge base of the internationalized Dutch economy) the visualization shows a recognizable representation of the Dutch industrial structure with a dominance of electro-technical and chemical applications and large multinational corporations. Although biomedical application integrates the patents they are not central to the whole set. These results strongly suggest that inferences of university-industry relations based on literature and patent analyses are heavily conditioned by the specificity of the biotechnology sector.

The question of the influence of the nature of the relations on the performance of the network is a debated issue addressed with social network analysis. The concepts of strong and weak ties were introduced by Granovetter (1973) and represent different forms of social capital. Strong ties represents strong and regular interactions and weak ties represent sporadic and temporary interactions.

Table 1: University-industry relations and social network analysis: main debates and conceptual propositions arising from the literature review

Main concepts	References (authors, year)	Conceptual propositions proposed by the literature
Patterns of university-industry relations	(Leydesdorff 2004, Gilsing and Duysters 2008, Krätke and Brandt 2008)	Biotechnology has a specific pattern of university-industry interaction, not generalizable to other fields; patterns of university-industry relations are influenced by regional industrial structures
Influence of commercial orientation on fundamental science production	(Balconi and Laboranti 2006)	Academics more connected to industry are more productive in scientific terms
Strong and weak ties, structural holes, social capital	(Gilsing and Duysters 2008, Rost 2011, van der Valk et al. 2011, Villanueva-Felez et al. 2013)	Balanced social structures (strong ties with some weak ties) seem to be more innovative; differential outcomes on the nature of knowledge contingent on the specific balance of the structure of social capital
"Small worlds" networks	(Balconi et al. 2004, van der Valk et al. 2011, Guan and Zhao 2013, Protogerou et al. 2013)	Networks with high clustering and short average geodesic paths are more conducive to inventive or innovative activity
Open-science and proprietary technology	(Balconi et al. 2004, Owen-Smith and Powell 2004)	The institutional attributes of open science and proprietary technology influences network structure; open science networks are more connected and dense than proprietary networks that are more fragmented and disperse
Knowledge base or environment as a relational factor	(Owen-Smith et al. 2002, Leydesdorff 2004, Gilsing and Duysters 2008, Krätke and Brandt 2008, Plum and Hassink 2011)	Different knowledge bases affect network structural properties, the position of individual entities in the network and their capacity to access knowledge
Public research organizations as central actors in innovation networks	(Breschi and Catalini 2010, Lissoni 2010, Minguillo and Thelwall 2012, De Stefano and Zaccarin 2013, Protogerou et al. 2013)	Academic authors-inventors assume more brokerage positions; public research organization are at the centre of innovation programmes
New methodological approaches	(Heimeriks et al. 2003, Kim 2012, Minguillo and Thelwall 2012)	Asides from patents indicators, other indicators and data unmask fundamental structural or relational properties
Triple-helix theory	(Heimeriks et al. 2003, Khan and Park 2013)	Triple helix assumptions on institutional role intersections are supported; multiple communication channels with differential roles in the Triple Helix relation
Industrial districts	(Morrison 2008, Capo-Vicedo et al. 2013)	Public research organization as main intermediaries of knowledge flows to the district; weak knowledge exchanges but strong information exchanges inside the district actors

Coleman (1988) claimed that cohesive groups and strong ties were effective ways to coordinate an exchange of knowledge flows, while Burt (1992) argued that strong ties resulted in redundant information and that innovation required new knowledge inflows and perspectives coming from weak ties. Villanueva-Felez et al. (2013) apply these concepts to assess in which way the structure of researchers' social capital affects academic performance. The authors distinguish between academics that are completely embedded in a network that has no weak ties (establishing links with members of his or her own department, without ties with government, industrial, or other societal actors), academics which are in a network that is formed predominantly by weak ties and academics that are in an integrated network that contains both strong and weak ties. The results show that the academics in the network with no weak ties are the less productive. On a study of a network of inventors and on the assessment of the impact of patents (based on forward citations) and integration of knowledge (based on backward citations), Rost (2011) concludes that inventors with balanced social capital (strong ties but also some weak ties) come up with the most innovative solutions, or integrate the most knowledge or have the highest impact on future knowledge. He concludes that Coleman's and Burt's perspectives are complementary and that in the presence of strong ties, weak network structures (structural holes or a peripheral position) leverage the strength of strong ties in the creation of innovation. Similar arguments are advanced in a visual network analysis of two government sponsored programmes that aimed to foster innovation through public-private partnerships (van der Valk et al. 2011) and also by other studies of university-industry relations or industry networks (Ahuja 2000, Gilsing and Duysters 2008)

UNIVERSITY-INDUSTRY RELATIONS AND INSTITUTIONAL OR INDUSTRY CONDITIONS

The analyses of patent databases provides the basis for the exploration of another important concept, which is debated in multiple forms and in its multiple consequences in studies of university-industry relations, which is the distinction between the characteristics of open science and proprietary technology (Merton 1957, Cowan and Jonard 2003). The debate can be inserted in a larger debate concerning the influence of diverse institutional conditions on processes of relations between organizational entities. Balconi et al. (2004) conduct a study of Italian academic and industrial inventors whereby, departing from assumptions on the behaviour or characteristics of "open science networks" and "proprietary networks", expect to find differences between the networks of academic and non-academic inventors. In fact, the study found that networks of industrial inventors are much more fragmented than networks of academic inventors, except in the chemistry field (defined in a broad sense, i.e. including biotechnology). The chemistry sector, a science-based field, was different because it was influenced by the institutional weight of scientific inputs in commercial technology.

The open science characteristics of scientific communities translate, in social network terms, into the so-called networks with "small worlds" characteristics (Albert and Barabási 2002). The small world properties, in the context of scientific networks in a specific discipline, are defined by the existence of a large component connecting almost all nodes, and within the large component all nodes (scientists) are close to each other (Newman 2001, Albert and Barabási 2002). These characteristics of academic networks are not found in networks of inventors, except in science-based fields. These results are coherent with the results of Leydesdorff (2004). The influence of small world properties on innovativeness is addressed in the study of industry networks (Verspagen and Duysters 2004) and in university-industry networks (Guan and Zhao 2013), and generally considered to be positive, although there are disagreements concerning this positive influence (Fleming et al. 2007).

Other articles support the importance of environmental factors in shaping specific properties of networks. A study of the Boston biotechnology sector (Owen-Smith and Powell 2004) found that the information flows between the actors of the network, which included firms and public research organizations, depended not only on network participation and position or geographic proximity, but also on the institutional characteristics of the network, that is, if the network was dominated by public organizations, with an open science culture, or by private entities, with a proprietary culture. In public-dominated networks firm performance depended only on net participation, unlike in networks dominated by private entities, where innovative performance depended on position factors, i.e., their closeness to central actors (although this characteristic was weak in terms of statistical significance).

An important determinant of cooperation between university and industry, and an important factor in terms of innovative performance, seems to be related to the position of the firm in the network. That position may be related to geography, in the sense that a firm that is located in a densely populated region is positively affected by the geography (Balconi and Laboranti 2006) or that position may be related to the knowledge base that the firm possesses and that may confer the firm the possibility to connect with more or less central actors of the network. A study of an industrial network in Germany (Cantner and Graf 2006) argues that a prerequisite for future cooperation is not based on past cooperation but rather on a shared knowledge base. As such, it questions ideas that argue that persistent cooperation, based on trust, is necessarily the basis for collaboration. Additionally it argues, based on regression analysis, that job mobility of scientist and engineers is a better predictor of relational structure than past collaboration.

In a study of two industrial networks (biotechnology and multimedia) in a period that was characterised by breaking with an existing dominant design and a shift away from rules, norms, routines or activities, Gilsing and Duysters (2008) argue that structural as well as relational network properties are influenced by environmental conditions. Environmental conditions related to the different knowledge bases and the validation and selection mechanisms inherent to each of the two fields explain the relational and structural properties of the two networks. For instance, the connections of public research organizations are (again) centrally present in the biotechnology field but absent in the multimedia field (Gilsing and Duysters 2008).
Differences in the knowledge base show up as an important factor in the determination of collaboration structures in another study involving biotechnology firms within a regional context (Plum and Hassink 2011). Besides indicating again the central position of public research organizations in industrial biotechnology networks, it points to differences related to internal competencies of the firms regarding differential capabilities in terms of the nature of the knowledge required to develop the differential products of each firm, in which the knowledge of the market also has a role.
Although In a quite different perspective, a study of the differences between the structures of two networks emphasises the importance of environment in shaping the properties of the network (Capellari and De Stefano 2014). Patents that are owned by the university (the university is the assignee) or invented by the university (the university is not the assignee but at least one of the inventors is a tenured academic), are analysed separately, showing differences in terms of size of components, number and size of subgroups and the brokerage position of inventors. The institutional factors are mediated by two universities that have different policies related to patenting ownership.

UNIVERSITY-INDUSTRY RELATIONS AND THEORIES OF INNOVATION AND ECONOMIC DEVELOPMENT

There is a strand of research of university-industry relations using social network analysis methods that adopt a deductive approach and try to validate some relatively entrenched conceptual implications of some theories.
One of the studies looks at the implications of the industrial district approach. Morrison (2008), in her study of the furniture sector in Italy, argues that the community of informal ties inside the district appears to be rather small and that ‘know how’ sharing is also rather limited, contrary to assumptions from industrial district theorists that based their ideas on the development of these concentrated regions on intense knowledge exchange between the actors. It, however, supports the argument that public research organizations, more than large firms, play a central role as intermediaries in the knowledge flows for innovation that occur in the industrial district, and that knowledge for innovation does not arise only from close interactions between the firms of the district, an idea that is also supported by a study of a Spanish textile industrial district (Capo-Vicedo et al. 2013).
The implications of the triple-helix approach are also examined. Using webometric indicators and semantic analysis of the contents of the webpages Kim (2012) found that university and industry websites were similar, thus suggesting there is an intersection or interchangeability of the roles and function of the two types of organizations, as suggested by the triple-helix theory (Etzkowitz and Leydesdorff 1998). Diverse channels of communication and relations between the diverse institutional actors (co-authorship, participation in projects, information diffusion) is also explored in Heimeriks et al. (2003) which argue that each communication channel or media has different functional purposes in the maintenance of the links of the triple-helix relation.

DESCRIPTIVE AND METHODOLOGICAL CONTRIBUTIONS

The central position of public research organizations shows up in descriptive analyses of networks that involve heterogeneous actors. Both a study of the network structure of science parks (Minguillo and Thelwall 2012), using web links as indicators of connections, and a study of the collaborative networks established during the seventh Framework Programme on Research and Technological Development of European Commission, show the central position of public research organizations. In the study of science parks, governmental agencies also play an important role, and in the case of the Framework Programmes, although firms are present in larger numbers, they are not the central actors.
Finally, there is a search for alternative methodological approaches and indicators in the studies of networks of university-industry relations. Some authors propose the use of webometric approaches (Kim 2012, Minguillo and Thelwall 2012) and other authors propose the use of simultaneous indicators of relational characteristics, such as citations, project participation, questionnaires or other data (Heimeriks et al. 2003, Furukawa et al. 2011, Almodovar and Teixeira 2014), arguing that analysis based on a single indicator underestimate the level and may not capture all of the complexities of the collaboration patterns.

CONCLUSIONS

The use of social network analysis in the study of university-industry relations was reviewed in this study. There are not many studies that combine the two perspectives and the ones that exist follow different research objectives and concerns and different methodological proposals. It seems evident that this particular knowledge quest is in a highly exploratory phase. Nevertheless, the contributions to knowledge have been varied and important, ranging from purely descriptive studies and methodological explorations to deductive testing of established theories. Some possible research paths are open. Eventually, the use of more complex and elaborated concepts of network analysis could improve the analysis of data, it may have the potential to reach different or stronger evidence and conclusions and it may be an aspect that must be improved. The diversity and plurality of university-industry relations has not been properly addressed in the literature, which tends to use patents as indicators of collaboration. Environmental and institutional influences of diverse sorts are clearly very important factors that condition and determine university-industry relations, and research is open to greater exploratory efforts. There is a considerable potential to test theoretical and conceptual propositions which are assumed but have scarce empirical support.

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