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Better connected, more reputable? On the association between node centrality and academic reputation in the European Union research and innovation networks

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ABSTRACT

Reputation is often overlooked in the geography of innovation studies, but may represent a relevant outcome of the participation in multi-scalar research and innovation networks. To date, a limited number of studies have outlined how collaborations in inter-organizational networks contribute to build academic reputation and scientific excellence, generally without distinguishing between the two concepts. This paper aims at assessing to what extent the degree of participation in the European Union nanotechnology network contributes to determine the reputation of universities as captured by renowned university rankings. Reputation is conceptualized as either the opinion of other academics about a given university ("academic reputation") or scientific achievements ("scientific excellence"). The findings presented in this paper suggest that cooperation in international inter-organizational networks is not only essential for securing research funds and acquiring new relevant knowledge but also for positively contributing to shape academic reputation and enhance scientific excellence.

KEYWORDS

higher education institutions, academic reputation, university rankings, innovation networks, research policy

1 | INTRODUCTION

Holding a central or key position in collaborative international research and innovation (R&I) networks is generally considered of vital importance for academic institutions. Among other things, being successful in such networks enables universities to secure research funds and acquire new resources and fresh ideas (Calignano, 2017). This study aims at understanding whether the degree of participation and strategic positioning in such networks lead to better academic reputation and scientific results. More specifically, I address the following research question: I) Are the node centrality and key positioning of universities in R&I networks associated with academic reputation and scientific excellence?

1.1 | Aims and main concepts used in the paper

Nowadays, R&I networks represent vital sources for academic institutions in terms of new acquired knowledge and financial resources (Calignano, 2017), although they may similarly have a considerable influence on reputation. Despite this, there is a limited number of published academic works on the geography of innovation and related fields that have examined the impact of inter-organizational interactions in shaping reputation. As mentioned above, this paper precisely aims at narrowing the gap in the literature on knowledge exchange and innovation dynamics by examining the possible association between the centrality and positioning of universities in R&I networks and reputation.

In recent decades, the university system has changed considerably in almost all countries. Among other things, public funding policies are mainly based on research performance (i.e., quantity and quality of publications, patenting and technology transfer activities; Foray & Lissoni, 2010) and academic researchers are now called to exploit economically the research they conduct (Schulze-Krogh & Calignano, 2019). Similarly, academics often need to acquire external resources to fund the research activities of their departments or laboratories. This latter aspect is intertwined with the substantial decrease in university funds provided by the various national governments (Muscio, Quaglione, & Vallanti, 2013), which have made international competition for research funds increasingly important. In this scenario, the European Union Framework Programmes (EU FPs) represent a critical funding source for higher education institutions, other than being the perfect arena for acquiring and exchanging new and valuable knowledge (Calignano, 2017). Indeed, regional and national policymakers are extremely interested in understanding which actually are the main outcomes of the multi-scalar R&I programmes funded under the EU through its main R&I policy action (Enger & Castellacci, 2016). Based on these premises, the present paper examines the theme "Nanosciences, Nanotechnologies, Materials and New Production Technologies" (NMP), funded under the Seventh Framework Programme (FP7-NMP), implemented in the 2007–2013 period, with the aim of seeking for an association between node centrality or key positioning and reputation of academic institutions.

Considerations regarding the importance of being competitive in international R&I networks, together with the relatively recent scholarly attention to the social and relational dimensions of innovation (Bathelt & Glückler, 2011), have given rise to a broad body of literature examining university linkages with external partners, as well as the characteristics of R&I networks at various geographical scales (e.g., van Egeraat, Kogler, & Cooke, 2014). Although some of these studies also take into account the characteristics of the actors making up such networks (see, among others, Calignano, 2017), most of the literature on the topic focuses on the knowledge flows engendered by the partnerships among the various types of organizations involved (i.e., universities, but also research centers, private companies, public authorities, etc.; e.g.,Calignano & Quarta, 2015; Scherngell & Barber, 2009). This is mainly due to the collaborative dimension of the research projects funded by international R&I

programmes such as the EU FPs, but it is also ascribable to a lack of data on the characteristics of organizations (Lepori, Veglio, Heller-Schuh, Scherngell, & Barber, 2015).

Although these previously published studies illuminate several important aspects related to the impact of multi-scalar innovation networks, little is said about the influence that such networks may have in shaping academic reputation and fostering excellence of scientific research. This topic is largely overlooked in the geography of innovation studies, even though it is of particular interest for academic managers. It is widely acknowledged that reputation is a critical factor for universities and that academic institutions aim at enhancing their image and reputational capital. In fact, among other things, reputation is an extremely important element for several reasons, such as gaining a "competitive advantage," influencing prospective students to enroll, building credibility and trust, and improving internationalization (QS World University Rankings, 2020). Consequently, this paper sheds light on a lesser studied topic by providing original and, hopefully, valuable findings.

In this regard, it is worth noticing that almost all the previous studies conducted on similar topics have considered reputation and academic excellence as overlapping terms (e.g., Enger & Castellacci, 2016; Lepori et al., 2015), even though they might represent two different aspects of the broader conceptualization of reputation, which also includes other personal parameters, in addition to the quantity and quality of scientific outputs (in this regard see, among others, Brewer & Zhao, 2010; Larsen, 2003). In other words, what can be hypothesized is that academic reputation mainly depends on a generalized perception of the quality of universities. Adopting this approach, I was able to distinguish between academic reputation and scientific excellence, and disentangle the way these concepts have been frequently operationalized in economic geography and innovation studies until now. In particular, with the term "academic reputation" I refer to the opinion that other academics have about a given university, while "scientific excellence" refers to the scientific productivity and, more generally, achievements of an academic institution. Based on this differentiation, through my research it was possible to determine in which sphere of reputation the impact of centrality or key positioning in R&I networks is mainly materialized (i.e., academic reputation, scientific excellence, or both).

1.2 | Structure of the paper

The paper is organized as follows. The literature on the main characteristics of R&I networks is reviewed in the second section, together with a focus on the way academic reputation and scientific excellence are conceptualized in this paper, and a sub-section is devoted to explain why the EU nanotechnology network is a particularly appropriate dataset for the purposes of my empirical analysis. The research design adopted for carrying out the empirical analysis, based on social network analysis (SNA) and econometrics, is outlined in the third section. The results of the empirical analysis are presented in the fourth section. Finally, the major results of the study are presented and the conclusions are drawn in the fifth and sixth sections, respectively.

2 | LITERATURE REVIEW

This section aims at providing theoretical insights and illustrating the main concepts that I use in my paper. In particular, I illustrate the knowledge exchange dynamics characterizing multi-scalar R&I networks that, according to my theoretical approach, contribute to shape the reputation of academic institutions. Moreover, I depict the concepts of "academic reputation" and "scientific excellence" I use and explain how they are operationalized in the present paper. Finally, I justify the choice of the

EU nanotechnology network as a useful and informative dataset for the purposes of my empirical analysis.

2.1 | Innovation networks and knowledge exchange dynamics

The so-called "relational turn" in economic geography emphasizes the social and relational dimensions of innovation activities (Bathelt & Glückler, 2011). This influential strand of literature examines the complex web of relations among various types of actors, agents, and institutions in considerable depth (see, among many others, Bathelt & Glückler, 2011; Calignano & Hassink, 2016), and reveals how the characteristics of different networks of relations influence the spatial and relational dynamics leading to knowledge exchange and potential innovation (Fløysand & Jakobsen, 2011). After almost two decades of theoretical contributions and empirical analyses, which have benefitted from insights provided by neighboring strands of literature (e.g., evolutionary economic geography and innovation studies; see Boschma, 2005; Fagerberg, 2005), there is little question that, nowadays, organizations rarely innovate in isolation and are generally embedded in systems and networks at various geographical scales (Dicken & Malmberg, 2001).

Although economic geographers have traditionally dealt with localized knowledge circulation, recent contributions to the field stress the importance of multi-scalar innovation networks (e.g., Calignano, Fitjar, & Hjertvikrem, 2019). In fact, the importance of international sources of knowledge and long-distance ties, in alternative to or in combination with local connections (Bathelt, Malmberg, & Maskell, 2004), is clearly demonstrated by a multitude of empirical analyses, some of which have been carried out in the context of the EU FPs (e.g., Calignano & Hassink, 2016; Scherngell & Barber, 2009).

The EU FPs explicitly adopt a transnational collaborative perspective and encourages multi-scalar interactions among the actors involved. The aim of the various EU programming cycles, originally launched in the period from 1984 to 1988, is to create transnational research and alliances among the actors possessing the most advanced resources and capabilities in highly innovative sectors (Roediger-Schluga & Barber, 2008).

As mentioned earlier, the FPs are considered the most important R&I policy implemented by the EU and represent, more now than ever (Schulze-Krogh & Calignano, 2019), a vital funding source for academic and research institutions located in the EU, as well as in most of the associated countries (e.g., Switzerland, Israel, and Norway). Many studies offer in-depth analyses of the R&I networks created within the EU FPs and provide detailed information on the spatial and relational characteristics of the knowledge flows created and fostered by the organizations involved (e.g., Calignano et al., 2019; Dotti & Spithoven, 2018).

These network analyses conducted at the node level demonstrate that the various EU R&I networks are characterized by a small number of clearly identifiable central actors and a stable core of connected nodes (Scherngell & Barber, 2009). The spatial dimension of knowledge exchange dynamics has been tackled even more often and in more depth by researchers who reveal how other dimensions of proximity (e.g., technological and social proximity) are apparently more important than the mere geographical proximity in the building of the research groups (Calignano, 2014; Scherngell & Barber, 2009). In addition, a core-periphery structure—in which the organizations located in the most innovative and competitive regions greatly benefit from technological diversity (Muscio & Ciffolilli, 2018), collaborate more often between each other (Cecere & Corrocher, 2015) and tend to occupy a central position (Balland, Suire, & Vicente, 2013)—can be generally observed in the EU R&I networks.

Regarding the topic tackled by the present paper, previous studies demonstrate that the R&I networks funded through the EU FPs lead to increased scientific productivity, especially when research groups are not too large (Breschi & Malerba, 2011), but very little is said on how they positively influence academic reputation. In general, the organizations that cooperate in funded joint research projects benefit from new knowledge, cognitive approaches, and scale economies in research activities. All these elements are deemed to enhance scientific productivity (DeFazio, Lockett, & Wright, 2009). However, although there is a wide consensus that collaborations established in the context of R&I networks have a positive effect on productivity at the level of individual researchers (Lee & Bozeman, 2005), the impact of such collaborations in the case of academic institutions as a whole is much more contested (Lee, Won, Choe, & Kim, 2012). According to Enger and Castellacci (2016), successful applicants in the EU FPs generally rely on previous successful experience and a stronger scientific reputation. In a slightly different, but related, context, Vogel, Hattke and Petersen (2017) observed that the probability of publishing papers in top academic journals increases considerably with the reputation of the institution to which authors are affiliated. By adopting an opposite perspective, DeFazio et al. (2009) suggest that the collaborations funded under the EU FPs have a positive effect on research productivity, but almost exclusively in the long run. In this regard, Leydesdorff and Wagner (2008) argue that participations in joint research projects lead to a growing co-authorship of scientific papers and that, particularly interesting for the purposes of the present paper, researchers link together precisely for reasons that are mainly related to acquiring resources, rewards, and reputation (Wagner & Leydesdorff, 2005). This seems to be further confirmed by Schütz, Schroth, Muschner, and Schraudner (2018: 50), according to whom academic institutions that participate in funded R&I networks "stand to benefit from the role of 'interaction enabler' via […] an improved academic reputation, and added credibility."

As specified in Section 1.1, most of the studies examining the characteristics and the scientific and socioeconomic impact of the EU FPs tend to privilege the study of the linkages established by the organizations involved. This is mainly due to the collaborative dimension of the projects funded under the FPs (Lepori et al., 2015). In fact, although several analyses at the node level have been carried out, also revealing interesting features of the organizations that play a central or strategic role in the EU networks (see the previously cited studies by Scherngell & Barber, 2009 and Calignano, 2017), the influence that network positioning may exert on some features of the organizations involved necessitates further investigation. Based on the limited literature on the topic, the association between node centrality or strategic positioning in the EU R&I networks and academic reputation or scientific excellence is definitely an element that deserves to be studied in more depth.

2.2 | Academic reputation and scientific excellence

The term "academic reputation" adopted in this paper refers to the way a university (or a department) is perceived by academics who work in other institutions (e.g., Lafuente-Ruiz-de-Sabando, Zorrilla, & Forcada, 2018; Larsen, 2003). This definition of "academic reputation" is not dissimilar from the concept of "public reputation" coined by Glückler and Armbrüster (2003: 279) for knowledge services (i.e., "the perception of a consulting firm's past performance" generally based on information which "circulates freely in the public domain").

Some renowned international university rankings (e.g., QS Ranking, Times Higher Education) try to capture academic reputation through specific surveys. In this regard, it must be noted that if, on the one hand, such rankings are based on the opinions of the surveyed academics, on the other hand, they themselves contribute to creating and reinforcing the reputations of academic institutions in the mind of the respondents (Larsen, 2003). In any event, what this study hypothesizes is that holding a central or key position in competitive funding schemes, such as the FPs periodically launched by the EU, is a critical factor in shaping the generalized perception of reputation, as captured by some rankings, in a given field (materials science, in the present case study).

Moreover, as discussed elsewhere in this paper, another aspect to consider is that academic reputation and scientific excellence do not necessarily overlap, since the latter refers to the actual (although imprecise; Anowar et al., 2015) quality of a university, while the former refers to how this quality is generally perceived. A useful addition in this regard is the report published by Radojicic, Jovanovic-Milenkovic, and Jeremic (2017), who found little correlation between number and quality of publications and academic reputation (i.e., scores of universities in the QS Ranking with specific regard to mathematics and medicine).[1]

Different rankings measure different dimensions of reputation. For instance, the specific component of the QS Ranking used in this paper collects data on the reputation of academic institutions based on the opinion of experts related to the quality of universities in many different fields (QS Ranking - Reputation), while others (i.e., the ARWU Ranking and its component ARWU citations) exclusively consider indicators of scientific productivity and impact. In other words, although considering narrow indicators, the ARWU Ranking is based on objective criteria, as opposed to the more subjective perception-based measure of the QS Ranking - Reputation, which can be considered an informative dataset and a good proxy for measuring academic reputation as conceptualized in this paper.

2.3 | Why the EU nanotechnology network?

Shattock (2017) reported a direct correlation between the growing importance of international university rankings and the "obsession" of academic institutions with achieving the status of "world class" university or considerably improving their ranking score. Despite the criticisms they receive (e.g., too much emphasis on research outcomes or, conversely, biased results toward certain countries when survey-based measurements are used), university rankings "have a powerful effect on the way institutions perceive themselves and are perceived by others" (Shattock, 2017, p. 9). Hence, trying to capture the relationship between the role that academic institutions play in international R&I networks and their reputation seems to be not simply a useful exercise, but a necessary tool for policymakers and academic managers. In this respect, nanotechnology is the perfect arena in which conducting the empirical analysis presented in this paper. Among other things, nanotechnology plays a key role in the EU R&I policies, which include microelectronics, nanoelectronics, nanotechnology, and advanced materials in the so-called Key Enabling Technologies, potentially allowing countries to use them to tackle major societal challenges (Calignano & Quarta, 2015). In addition, the FP7-NMP has often been chosen as a case study, since research at the nanoscale level is considered an irruptive interdisciplinary field enabling scholars to detect innovation dynamics at various geographical scales and in several sectors. This view stems from the fact that nanotechnology can be successfully applied in many different high-technology (e.g., biotechnology, information, and communication technology) and traditional (textile, ceramics, food, etc.) industries (Calignano & Quarta, 2015; Pandza et al., 2011). In addition, nanotechnology is characterized by analytic knowledge bases (i.e., science-based industries, which primarily rely on codified knowledge; Asheim & Gerlter, 2005), meaning that the effects of joint research projects are largely materialized in the form of scientific publications. This peculiarity of nanotechnology makes our database an interesting and reliable source for testing research productivity, or more broadly scientific excellence (ARWU Ranking and ARWU Citations), in addition to capturing academic reputation through the aforementioned specific component of the QS Ranking.

3 | RESEARCH DESIGN

In this section, I delineate the research design adopted in my empirical analysis. Specifically, in the next three sub-sections I describe the econometric model and all the variables employed. Further information on such variables is provided in Appendix A.

3.1 | Description of the model

SNA and econometric models are applied to investigate the association between the degree and characteristics of university participation in international R&I programmes and academic reputation. The dependent variables in the econometric model are the specific scores of the survey measuring reputation included in the QS Ranking – Materials Science and the ARWU Ranking – Materials Science (as a whole and one of its subcategories, i.e., ARWU Citations). Independent variables, such as centrality measures (degree, eigenvector, betweenness) and ego networks (structural holes) applied to the surveyed universities, and a set of control variables are used for carrying out the empirical analysis. Based on the characteristics of the dependent variables (i.e., eight ordinal variables; see Section 3.2 and Appendix A for details), ordinal regression is applied and various models related to FP7-NMP are proposed for testing my hypothesis, according to which R&I networks play a key role in shaping academic reputation and enhancing scientific excellence.

Potential endogeneity must be taken into consideration. The question is whether the position in the surveyed R&I network affects reputation or reputation affects the EU project participation. However, this potential reverse causality is definitely mitigated by the fact that reputation, as captured by the rankings, was measured at a later time than participation in the FP7-NMP (i.e., 2018)[2]. Based on the literature on the topic, the 5-year period after the end of the FP under analysis (which was concluded in 2013) was deemed to be an appropriate lapse of time for seeing the effects of the participation in funded joint research projects materialized (on the time necessary to develop reputation, see Roberts & Dowling, 2002 and Vogel et al., 2017; on the lifecycles of citations of research articles see, among others, Galiani & Gálvez, 2017; Table 1 and Endnote 2 for further details).

Occasionally, within a single variable, only data referring to different years were available and employed. This is the case for control variables, such as gross domestic expenditure on R&D at the country level and university size. Although this aspect might lead to statistical bias, it is considered a minor issue, since it actually applies to very few countries and academic institutions. Moreover, this type of data is generally characterized by a certain degree of stability, and relevant differences can be

TABLE 1 Spearman's rank correlation coefficient. Data sets: QS ranking-materials science (Years: 2016–2018) and ARWU Ranking-Materials Science (2017–2019)

QS ranking				ARWU ranking			
	Year 2016	Year 2017	Year 2018		Year 2017	Year 2018	Year 2019
Year 2016	1.000	0.892[a]	0.876[a]	Year 2017	1.000	0.936[a]	0.813[a]
Year 2017		1.000	0.928[a]	Year 2018		1.000	0.826[a]
Year 2018			1.000	Year 2019			1.000

[a]Correlation is significant at the 0.01 level.

observed only in the medium to long term. All the variables included in the models are described in detail in the following sub-sections and in Appendix A.

3.2 | Dependent variables

As explained above, the scores of a specific component (i.e., “Reputation”) contributing to the general QS Ranking - Materials Science are used as a proxy of academic reputation. More specifically, the QS Ranking aims at determining the reputation of academic institutions based on various indicators (e.g., citations per paper, H-Index, etc.), even though a survey collecting data on academic opinion about the quality of world’s universities in many different fields accounts for 40% of the overall score[3]. This specific indicator can be analyzed in isolation and used as a single indicator, as in the present case study. Following the QS Ranking – Materials Science (Reputation), an ordinal variable with eight tiers is used to classify the surveyed universities (see Appendix A for details).

Moreover, the ARWU Ranking – Materials Science is adopted for measuring Scientific Excellence. The ARWU Ranking is comprised of five different indicators related to scientific performances and merit, as illustrated in Appendix A. Here, the overall score and a specific component (ARWU Citations) are employed in the econometric analysis (i.e., eight ordinal variables in both cases).

3.3 | Independent variables

I have reconstructed a case-by-case matrix (adjacency matrix) related to the FP7-NMP, in which the universities participating in the FP under analysis represent the cases, based on the databases available on the CORDIS (Community Research and Development Information Service) website. I have surveyed all the universities located in the EU, in associated (e.g., Switzerland, Israel and Norway) and in relatively proximate countries from the geographical viewpoint (e.g., Russia and Turkey), which participated at least once in the FP7-NMP. Based on these parameters, I have excluded leading countries in the international nanotechnology arena (e.g., the United States and China). This decision was also influenced by the limited number of participants located in the latter countries.

Only universities were considered. I do not include institutions exclusively devoted to research in the final dataset, since they are generally not surveyed in the QS Ranking and ARWU Ranking. University hospitals are merged with universities when clearly affiliated with the latter. Overall, I have surveyed 585 universities. Two universities are considered as connected to one another if they participated in at least one joint project in the FP7-NMP.

I use various SNA measures, such as degree, eigenvector, betweenness and structural holes, to measure the centrality or a given node position in the network under analysis (see Hanneman & Riddle, 2005). In particular:

- Degree refers to the sum of ties that a university has established in the FP7-NMP. Hence, the academic institutions with the highest numbers of ties are considered the most important or central;
- Eigenvector is used for measuring the influence that a university has within the targeted networks. In eigenvector centrality, ties with high-scoring nodes count more than ties with low-scoring nodes. This way, eigenvector can be also seen as a means for determining the prestige of organizations involved in the university networks under investigation;
- Betweenness depends on the probability that a node lies along all the possible paths connecting the actors making up a network. This means that organizations with higher betweenness centrality

have a privileged position in networks. They sustain the whole network and, at the same time, exercise a sort of control on the other nodes by managing and filtering relevant information and knowledge from different sources. Moreover, betweenness centrality seems to be a better predictor of preferential attachment (i.e., the mechanism through which new nodes tend to attach to existing well-connected nodes; Barabási & Albert, 1999) than other centrality measures (Abbasi, Hossain, & Leydesdorff, 2012);

- A structural hole can be observed when a given node represents the only connection between other actors, thus acting as a "broker" (Burt, 1992). According to Snow and Fjeldstad (2015), a structural hole can benefit from its position in two ways: first, having access to information, knowledge, and resources that are not universally held and, second, playing actors off against each other in the competition for resources.

As mentioned earlier, degree, eigenvector, betweenness, and structural holes represent the independent variables in the econometric models adopted in the present paper.

3.4 | Control variables

In addition, University Size (four categories based on the number of students) and R&D expenditure at the regional level (R&D Expenditure) were used as control variables. With regard to University Size, the overall number of students is applied due to the lack of helpful and undoubtedly more accurate information at the department level. Despite this, the overall number of students is considered a good proxy for capturing the internal administrative capacity and the external capacity or attractiveness of a university (see Sciacca, 2013). Other control variables include the countries where the universities are located (i.e., fixed effects/dummy variables, with the last country of the list, i.e., the United Kingdom, used as reference category) and EU Membership (eight categorical variables determining whether a country is an EU member and how long it has been one).

The robustness of the econometric analysis is checked against alternative models. In this test, only universities located in the EU countries are considered (514 observations vs. 585 observations of the main econometric models). A variable such as Founding Year (four categorical variables) is added to the model, while R&D expenditure at the national level replaces the same variable at the regional level used in the main model. In addition, I use a binary variable for differentiating between the EU countries which joined the EU before and after 2004 (i.e., the year in which the largest number of Eastern European countries joined the EU simultaneously). Further specifications and more detailed information on the variables adopted for carrying out the robustness testing can be found in Appendix A.

4 | THE EMPIRICAL ANALYSIS: ACADEMIC REPUTATION AND NODE CENTRALITY IN THE EU FPs

In this section, I present the main results of my empirical analysis. In particular, I reveal some relevant network statistics and information on the network created by the academic institutions involved in the FP7-NMP. Subsequently, I show that a clear association between SNA measures and reputation exists, thus enabling me to argue that holding a central or key position may, in R&I innovation, contribute to shape academic reputation and scientific excellence.

4.1 | Network statistics and measures

Table 2 reports some general network statistics. Specifically, the "density" of a network is calculated by dividing the actual number of ties with the maximum number of possible linkages (Hanneman & Riddle, 2005) and provides a measure of network cohesion. The network density in the FP7-NMP is low (0.030, i.e., 3% of connected universities). The average degree, that is, the average number of connections with other universities, is 17.5.

The low density observed in the network suggests that the knowledge exchange between the universities that participated in the FP under analysis is not widespread and primarily involves some core organizations. This is demonstrated by the graph displayed in Figure 1. In this graph, the size of the circles shows the degree of participation of each university (i.e., the bigger the circle, the higher the degree), while the universities that make up the network core are placed at the center of the figure and highlighted more intensely. The lines showing the relations among the organizations were removed for graphical purposes and in consideration of the fact that linkages are not considered in the present study. Finally, the disconnected nodes (circles) are not included in the figure due to their high number, which is reported top right in numerical form (99 disconnected nodes, i.e., 19.2% of the total). Some clearly identifiable bigger circles make up the network core, while a high number of organizations are characterized by lower levels of participation or are completely disconnected from the relational network. Previous studies revealed similar core-periphery structures and related highly concentrated knowledge exchange when all of the different types of organizations (universities, research centers, private companies, public authorities, industrial associations, etc.) were surveyed (e.g., Balland et al., 2013; with specific regard to the EU nanotechnology network, see Calignano & Quarta, 2015).

Looking at the organizations showing the 15 highest scores related to the participation in the FP7-NMP, we can see that 9 of 39 surveyed countries fall in this portion of the ranking. Larger countries, such as the United Kingdom, Germany, Italy, and France, are represented, as are innovative and competitive smaller countries such as Sweden, Denmark, the Netherlands, Switzerland, and Belgium. The rankings for single organizations in this category are relatively stable regardless of the SNA measure applied. In fact, the same organizations can be found in the top 15 ranking related to degree and eigenvector centrality, while 16 of 17 organizations[4] similarly appear in the ranking related to betweenness (the only exception is represented by Utrecht University, which is replaced by Uppsala University). Differently, major differences can be observed in the universities that make up the ranking related to structural holes. Six universities listed in the previously examined rankings do not appear in this case (i.e., Trinity College, Lund University, The University of Manchester, Karlsruhe Institute of Technology, Utrecht University and Delft University of Technology) and are replaced by organizations showing moderate (National Technical University of Athens) or even low scores in the rankings related to the centrality measures applied (e.g., École Nationale Supérieure de Chimie de Lille, Limerick Institute of Technology, Ozyegin University, just to mention a few). Regarding the single organizations involved, the existence of a well-identifiable core of leading organizations which include, among others, Technical University of Denmark, École Polytechnique Fédérale de

TABLE 2 Network measures and statistics. Data set: FP7-NMP. Data elaboration: Ucinet (Borgatti, Everett, & Freeman, 2002).

FP7-NMP		
Density	**No. of ties**	**Avg. degree**
0.030	10,236	17.5

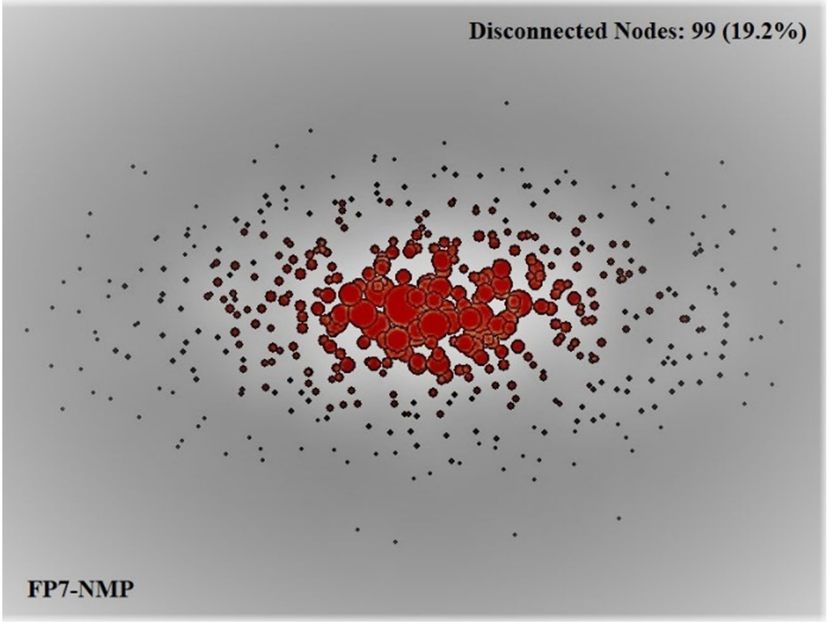

FIGURE 1 Network visualisation (FP7-NMP). Circle size = Degree. Data elaboration: Ucinet and NetDraw (Borgatti et al., 2002)

Lausanne, University College London, Katholieke Universiteit Leuven, University of Cambridge and ETH Zurich, can be clearly seen (see Table 3 for details).

4.2 | The econometric analysis: seeking for an association between SNA measures and reputation

Once the level of cohesion, the core-periphery structure of the reconstructed network and the top organizations in the FP under analysis are revealed; the existence of an association between node centrality or key positioning in international R&I programmes and the scores in one of the rankings used in this paper (QS Ranking, ARWU Ranking and ARWU Citations) are investigated.

All of the organizations listed in Table 3 were included either in the QS Ranking or ARWU Ranking, and, in 15 of 17 cases, they were ranked in both rankings. The only exceptions in this regard are represented by Eindhoven University of Technology and Lund University, which were included only in the latter ranking (see Table 3). Moreover, such a tendency is confirmed even if we consider a longer list of organizations scoring high in the FP7-NMP. For example, if we refer to degree centrality and extend the analysis to the top 100 universities, a very high number of them are ranked in the Top 500 universities in materials science, either by the QS Ranking or ARWU Ranking (84 of 100). This preliminary finding reveals the existence of an association between the level of participation in the EU FPs and being ranked in one of the two university rankings under analysis. The results of the correlation analysis, shown in Table 4, clearly confirm that a higher level of participation (degree centrality) in the FP7-NMP is positively correlated with a higher score in either the QS Ranking or ARWU Ranking (including ARWU Citations). Similarly, the targeted rankings show a positive and

TABLE 3 Top 15 scoring organizations in the FP7-NMP. Dataset: FP7-NMP. Data elaboration: Ucinet (Borgatti et al., 2002)

Rank	Country	Country	QS ranking	ARWU ranking	Degree	Eigenvector	Betweenness	Structural holes
1	Technical University of Denmark	DK	1–50	76–100	166	0.212	5.089	0.849
2	École Polytechnique Fédérale de Lausanne	CH	1–50	1–50	127	0.165	3.495	0.834
3	University College London	UK	76–100	101–150	119	0.166	2.342	0.807
4	Katholieke Universiteit Leuven	BE	1–50	201–300	115	0.142	2.279	0.847
5	University of Cambridge	UK	1–50	51–75	106	0.147	2.339	0.815
6	ETH Zurich	CH	1–50	201–300	104	0.148	2.116	0.800
7	Eindhoven University of Technology	NL	–	151–200	104	0.134	2.278	0.823
8	Trinity College Dublin	IE	151–200	51–75	96	0.132	1.922	0.797[a]
9	Lund University	SE	–	301–400	91	0.134	1.235	0.778[a]
10	RWTH Aachen University	DE	1–50	201–300	90	0.126	2.148	0.806
11	The University of Manchester	UK	1–50	101–150	90	0.133	1.249	0.773[a]
12	Karlsruhe Institute of Technology	DE	1–50	201–300	89	0.137	1.770	0.801[a]
13	Polytechnic University of Turin	IT	101–150	151–200	87	0.114	2.021	0.819
14	University of Nottingham	UK	151–200	201–300	84	0.111	1.670	0.812
	Utrecht University	NL	101–150	76–100	84	0.125	1.142[a]	0.760[a]
15	Delft University of Technology	NL	1–50	101–150	80	0.114	2.822	0.791[a]
	TU Dresden	NL	1–50	201–300	80	0.102	2.065	0.815

Abbreviations: BE, Belgium; CH, Switzerland; DE, Germany; DK, Denmark; IE, Ireland; IT, Italy; NL, The Netherlands; SE, Sweden; UK, United Kingdom.

[a]Not ranked in the Top 15 scoring organizations.

TABLE 4 Spearman's rank correlation coefficient. Data sets: FP7-NMP, QS Ranking-Materials Science (Reputation), ARWU Ranking-Materials Science (Overall) and ARWU Ranking-Materials Science (Citations).

	Degree FP7	Eigenv. FP7	Between. Fp7	Structural Holes FP7
QS_Ranking	0.441[a]	0.489[a]	0.510[a]	0.510[a]
ARWU Ranking	0.479[a]	0.529[a]	0.545[a]	0.545[a]
ARWU Citations	0.491[a]	0.531[a]	0.550[a]	0.553[a]

[a]Correlation is significant at the 0.01 level.

not dissimilar correlation with all of the other independent variables adopted in this study (i.e., eigenvector, betweenness, and structural holes).

In addition to this, ordinal regression is used for determining the association between the various centrality measures (degree, eigenvector, and betweenness) or ego networks (structural holes) applied and QS Ranking, ARWU Ranking, and ARWU Citations. As specified above, a set of control variables is included in the proposed econometric models to account for the characteristics of universities (size), as well as socioeconomic and institutional factors at the regional and country level (R&D expenditure and EU membership age), which can similarly play a role in shaping the reputation or fostering the scientific excellence of a given university in the geographical context in which I conducted my empirical analysis (see Appendix A).

The results of the Models 1-12 shown in Table 5 confirm that all of the SNA measures adopted (degree, eigenvector, betweenness, and structural holes) are positively associated with academic reputation (QS Ranking). Similarly, all of these centrality measures and ego networks are statistically significant and positively correlated with ARWU Ranking and ARWU Citations, which I use in this paper as a proxy of scientific excellence. R&D Expenditure is statistically significant and positively correlated with all of the models related to the QS Ranking, while it similarly shows a positive—albeit not statistically significant—association with the ARWU Ranking and ARWU Citations. Regarding ARWU Ranking, the only exception is the statistically significant correlation between R&D Expenditure and the probability that a university lies on paths between other universities (betweenness centrality). EU Membership is positively correlated with academic reputation and scientific excellence, but is not statistically significant. Finally, the university size is always positively associated with academic reputation (QS Ranking) and scientific excellence (ARWU Ranking and ARWU Citations).

4.3 | Robustness check

A check on the robustness of the applied models is performed by considering the association between node centrality (degree, eigenvector, and betweenness) or strategic positioning (structural holes) and QS Ranking and ARWU Ranking. Only universities located in the EU regions which participated in the FP7-NMP are included in the alternative models. Some variables are changed with the aim of testing the robustness of the econometric analysis against alternative models. In particular, a variable such as the founding year of the surveyed institutions is added since it may represent a driver of reputation (see Geuna, 1998 in this regard). Moreover, a dummy variable is used to determine whether the countries where universities are located joined the EU before or after 2004 (i.e., the year of the largest single expansion of the EU). Finally, R&D Expenditure at the country level is used instead of the same

TABLE 5 Ordinal regression with country fixed effects (reference country: United Kingdom). Dependent variables: QS Ranking-Materials Science (Reputation) (Models 1–4), ARWU Ranking-Materials Science (Overall) (Models 5–8), ARWU Ranking-Materials Science (Citations) (Models 9–12).

	Model 1 (QS)	Model 2 (QS)	Model 3 (QS)	Model 4 (QS)	Model 5 (ARWU)	Model 6 (ARWU)	Model 7 (ARWU)	Model 8 (ARWU)	Model 9 (ARWU Citations)	Model 10 (ARWU Citations)	Model 11 (ARWU Citations)	Model 12 (ARWU Citations)
Degree FP7	0.061[a] (0.007)				0.053[a] (0.005)				0.043[a] (0.005)			
Eigenvector FP7		0.377[a] (0.037)				0.338[a] (0.028)				0.248[a] (0.025)		
Betweenness FP7			2.791[a] (0.320)				2.587[a] (0.276)				1.556[a] (0.213)	
Structural holes FP7				0.097[a] (0.009)				0.086[a] (0.007)				0.061[a] (0.006)
University size	0.747[a] (0.187)	0.608[a] (0.192)	0.902[a] (0.187)	0.632[a] (0.191)	0.741[a] (0.131)	0.647[a] (0.132)	0.858[a] (0.130)	0.676[a] (0.132)	0.724[a] (0.131)	0.637[a] (0.132)	0.825[a] (0.130)	0.663[a] (0.131)
R&D expenditure (NUTS 1 - 2)	0.448[a] (0.129)	0.400[a] (0.135)	0.435[a] (0.126)	0.344[b] (0.135)	0.185 (0.098)	0.150 (0.100)	0.193[b] (0.097)	0.093 (0.102)	0.134 (0.096)	0.085 (0.098)	0.157 (0.095)	0.057 (0.099)
EU membership	2.514 (549.5)	2.482 (524.9)	2.543 (574.8)	2.502 (569.1)	2.649 (631.9)	2.641 (614.8)	2.651 (640.4)	2.544 (640.2)	2.643 (630.1)	2.627 (618.8)	2.664 (638.1)	2.573 (638.6)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
- 2 Log Likelihood	645.4[a]	602.2[a]	639.2[a]	597.5[a]	1,126.4[a]	1,064.1[a]	1,095.0[a]	1,059.7[a]	1,139.2[a]	1,110.4[a]	1,149.9[a]	1,109.3[a]
Pseudo R-squared	0.414	0.479	0.415	0.481	0.429	0.496	0.437	0.496	0.390	0.426	0.361	0.420
Obs.	585	585	585	585	585	585	585	585	585	585	585	585

Standard errors in parentheses.

[a]Statistically significant at the 0.01 level.

[b]Statistically significant at the 0.05 level.

variable referring to the regional level in the main econometric models. Further details on the new measures adopted in the alternative models are provided in Appendix A.

Overall, no significant differences can be observed in these new models compared with the main ones (see Table 6). The founding year of an institution is statistically significant and positively correlated with scientific excellence, but not with academic reputation. EU Membership is positively correlated and statistically significant in all of the models proposed (with the exception of Model 1, in which QS Ranking is the dependent variable and degree centrality is the independent variable), while R&D Expenditure at the national level is either positively or negatively correlated with academic reputation and scientific excellence, but, in any case, not statistically significant. Finally, university size and, more importantly, node centrality (degree, eigenvector, and betweenness) and positioning (structural holes) in the FP7-NMP remain statistically significant and positively correlated with QS Ranking and ARWU Ranking even when alternative models are adopted. Hence, this further corroborates the hypothesis according to which a clear association between node centrality or strategic positioning in R&I networks and academic reputation and scientific excellence exists.

5 | DISCUSSION OF THE MAIN RESULTS

In this section, I discuss the main findings achieved through empirical analysis in light of the extant literature on the topic and the working hypotheses.

Academic institutions consider competitive international funding schemes such the EU FPs to be critical resources for funding the research activities of their laboratories and departments (Foray & Lissoni, 2010; Muscio et al., 2013; Schulze-Krogh & Calignano, 2019). In addition to this, the hypothesis advanced in this paper is that collaborations established in the context of multi-scalar R&I networks may similarly play a key role in shaping the reputation of academic institutions as well as enhancing scientific excellence. Hence, this paper contributes to the academic debate on the impact of funded collaborative projects on reputation in these two different forms and aims at providing policymakers and academic managers with some clear, and, hopefully helpful, indications.

The papers previously published on the topic led to somehow divergent findings. In fact, some scholars argue that collaborating in the context of R&I networks has a positive effect on productivity at the level of individual researchers (Lee & Bozeman, 2005), although a similar positive effect at the organizational level is not clearly demonstrated (Lee et al., 2012). Interestingly, DeFazio et al. (2009) revealed that the collaborations fostered by the EU FPs positively affect research productivity, but primarily in the long run. Until now, only a limited number of studies have focused on the impact that participations in R&I may have in terms of research outputs, and even fewer empirical analyses have considered how collaborations in joint research projects affect academic reputation. In this regard, it is worth mentioning the study conducted by Wagner and Leydesdorff 2005, according to whom researchers cooperate between each other precisely for enhancing their reputation. Finally, a recent study conducted at the organizational level revealed how one of the main motivations for academic institutions in joining research consortia is improving academic reputation and strengthening their credibility (Schütz et al., 2018).

What the present study adds to the extant literature is that holding a central or key position in R&I networks is clearly associated with both academic reputation (as perceived by other academics and measured through the QS Ranking - Reputation) and scientific excellence (measured through the ARWU Ranking and one of its components, i.e., ARWU Citations). In more detail, it is noteworthy that all of the universities listed in the top 15 organizations in terms of participation, and 84 of 100

TABLE 6 Robustness check—ordinal regression. Dependent variables: QS Ranking-Materials Science (Reputation) (Models 1–4), ARWU Ranking-Materials Science (Overall) (Models 5–8)

	Model 1 (QS)	Model 2 (QS)	Model 3 (QS)	Model 4 (QS)	Model 5 (ARWU)	Model 6 (ARWU)	Model 7 (ARWU)	Model 8 (ARWU)
Degree FP7	0.066[a] (0.007)				0.062[a] (0.006)			
Eigenvector FP7		0.280[a] (0.028)				259[a] (0.023)		
Betweenness FP7			2.124[a] (0.250)				2.166[a] (0.233)	
Structural holes FP7				0.081[a] (0.008)				0.077[a] (0.007)
University size	0.640[a] (0.203)	0.637[a] (0.203)	0.776[a] (0.190)	0.674[a] (0.202)	0.560[a] (0.140)	0.558[a] (0.140)	0.722[a] (0.136)	0.590[a] (0.140)
Founding year	0.081 (0.117)	0.089 (0.117)	0.144 (0.110)	0.089 (0.117)	190[b] (0.086)	0.188[b] (0.086)	0.232[a] (0.083)	0.202[b] (0.085)
R&D expenditure (NUTS 0)	−0.004 (0.192)	−0.054 (0.192)	0.109 (0.185)	0.036 (0.191)	0.220 (0.149)	0.213 (0.149)	0.273 (0.145)	0.228 (0.148)
EU membership (Dummy)	1.418 (0.745)	1.478[b] (0.744)	1.515[b] (0.744)	1.412 (0.746)	1.158[a] (0.443)	1.193[a] (0.445)	1.224[a] (0.429)	1.143[a] (0.440)
Country fixed effects	No	No	No	No	No	No	No	No
- 2 Log likelihood	548.5[a]	567.4[a]	602.4[a]	570.1[a]	978.8[a]	999.2[a]	1,003.4[a]	982.8[a]
Pseudo *R*-squared	0.406	0.404	0.343	0.402	0.426	0.422	0.381	0.426
Obs.	514	514	514	514	514	514	514	514

Standard errors in parentheses.

[a]Statistically significant at the 0.01 level

[b]Statistically significant at the 0.05 level.

most participating organizations in the FP7-NMP, are ranked among the Top 500 organizations by the QS Ranking (Reputation)—and ARWU Ranking—Materials Science.

Additionally, the application of SNA methods and techniques allows me to reveal the main structural features that characterize the network created by the universities involved in the FP7-NMP. As already observed in previous studies (see Calignano, 2014), only larger or dynamic countries and clearly identifiable organizations make up the core of the EU nanotechnology network, which, in turn, shows a clear correlation with the reputation of the closely tied organizations that comprise up. This very relevant finding is further strengthened by the econometric models applied, which confirm how node centrality and key positioning are positively associated with academic reputation and scientific excellence. In other words, elements such as the overall amount of participation (degree), links with more prestigious organizations (eigenvector), occupying a "privileged" position in the network (betweenness) and acting as a "broker" seem to have a positive influence on the image projected by a university, in addition to contributing to its research productivity and quality.

6 | CONCLUDING REMARKS

Having systematized the major findings of the present study in the previous section, some final reflections on how this study contributes to the academic and policy debates are needed.

From a methodological perspective, the combination of SNA and econometrics demonstrates to be a particularly appropriate research strategy for detecting the association between participation in R&I networks and reputation. Additionally, in this paper I make a clear distinction between academic reputation and scientific excellence, two concepts that are frequently used as synonyms in previous research on the topic (e.g., Enger & Castellacci, 2016; Lepori et al., 2015), while they do not necessarily overlap. Fame, legacy, image in the media, university infrastructures, and personal relationships, in addition to teaching and research, are only some of the potential factors that can shape the perception and related opinion about a university (on this topic, see Brewer & Zhao, 2010, among many others). As a consequence, all of these elements should be taken into careful consideration by academic managers when trying to bolster the images of their institutions (e.g., Larsen, 2003). What this study clearly brings to light is that a high degree of participation and strategic positioning may contribute to shape academic reputation (position in the QS Ranking), in addition to increasing research productivity and quality (ARWU Ranking and ARWU Citations). Hence, academic managers are called on to promote and support the applications of their affiliates in the competitive funding schemes periodically launched by the EU, not only for securing vital external funding, but also for strengthening the image and positive opinion of the universities that they represent.

From a complementary perspective, the EU evaluators should take into consideration how their decisions on the received applications may have an influence on the reputation of academic institutions. In this regard, an additional participation in an FP project might have little influence on the reputation of a larger, older and already reputable institution, but may have a significant impact on the status of smaller or peripheral universities. In this regard, Ukrainski, Kanep, Kirs, and Karo (2018) argue that less reputable universities should try to join consortia coordinated by prestigious institutions. This leads some scholars to assert that "[r]esearchers and institutions with less reputation should work on building up their networks and become members of consortia coordinated by more experienced institutions" (Dávid, 2016, p. 64). What is certain is that appropriate policy actions are needed. These policies should aim at fostering not only a more balanced distribution of research funds, but also at enhancing the degree of participation of organizations that do not score particularly well in the rankings related to the SNA measures applied in this paper. For example, promoting the inclusion of at least one of these marginally involved universities in some research consortia related to given research programmes might be an option. It should be considered that, from a geographical viewpoint, these organizations are often located in regions or countries that are characterized by less developed research and education systems and that, consequently, their higher engagement would be definitely beneficial in several respects (including their enhanced reputation and credibility), in addition to positively contributing to the effectiveness of the European Research Area (i.e., a policy measure which aims at integrating the scientific resources of the EU).

Although able to provide several findings and insights about the association between academic reputation and the centrality or position of academic institutions in innovation networks, this study is not exempt from limitations, the most important of which is that, like almost all of the previous studies on the topic (e.g., Enger & Castellacci, 2016; Lepori et al., 2015), this one relies on data from surveyed universities only. Including all of the other types of organizations (research centers, private companies, industrial associations, etc.) might lead to different results in terms of node centrality and position. In this regard, it is relatively easy to measure the reputation of larger firms, since specific databases are available, but remains practically impossible to check for the myriad of SMEs involved in the EU FPs. Future studies and, prior to those, surveys collecting data on the EU innovation networks should deal with this issue and, possibly, solve it.

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ENDNOTES

[1] Spearman's Rank between QS Ranking - Reputation (2018) and ARWU Ranking (2018) shows a moderate correlation (i.e., 0.597, statistically significant at the 0.01 level).

[2] The QS Ranking and ARWU Ranking related to materials science are available for 2016-2018 and 2017-2019 only, that is, a few years after the end of the FP7-NMP, and do not show significant differences throughout the period considered. Hence, I use the most recent data available for both rankings (i.e., those for 2018; see Table 1).

[3] Overall, 74,651 academics were interviewed in 2016, 2.1% of whom were experts in the field of materials science (1,568 respondents). Although there are no figures available on the total number of interviewees in the field of materials science in 2018, a graph published on the QS website shows that the total number of respondents increased in the transition from 2016 to 2018 (QS World University Rankings, 2019).

[4] There are 17 organizations in the top 15 rankings because some organizations showed the same degree and were both included in the list. Specifically, these institutions are the University of Nottingham and Utrecht University (84 participations) and Delft University of Technology and TU Dresden (80 participations).

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APPENDIX A

Dependent, independent and control variables (Main econometric models and robustness check). Name, indicators and description.

Econometric Models		
Dependent Variables	**Indicator**	**Description**
Academic Reputation	QS Ranking	Position of a university in the QS Ranking (Subject: Materials Science). Ordinal variables: Not Ranked = 0; 401–500 = 1; 301–400 = 2; 201–300 = 3; 200–151 = 4; 150–101 = 5; 100–76 = 6; 75–51 = 7; 50–1 = 8. Source: QS Ranking—Reputation Survey. Year: 2018.
Scientific Excellence	ARWU Ranking	Position of a university in the QS Ranking. Index based on five indicators: i) Number of papers authored by an institution in materials science, ii) Category Normalized Citation Impact, iii) International collaborations, iv) Number of papers published in top journals, v) Total number of the staff of an institution who have won a significant award since 1981. Ordinal variables: Not Ranked = 0; 401–500 = 1; 301–400 = 2; 201–300 = 3; 200–151 = 4; 150–101 = 5; 100–76 = 6; 75–51 = 7; 50–1 = 8. Source: ARWU Ranking. Year: 2018.
Scientific Excellence	ARWU Citations	Category Normalized Citation Impact (CNCI) is the ratio of citations of papers published by an institution in an academic subject during the 2013–2017 period to the average citations of papers in the same category, of the same year and same type (Ordinal variables). Year: 2018
Independent Variables	**Indicator**	**Description**
Participation FP7-NMP	Degree FP7-NMP	Degree Centrality: Number of connections established by each organization in the FP7-NMP. Source: CORDIS.

Continues

APPENDIX A (Continued)

Econometric Models		
Dependent Variables	**Indicator**	**Description**
Eigenvector FP7-NMP	Eigenvector FP7-NMP	Eigenvector Centrality: Measuring the "influence" of nodes in the network. Eigenvector shows how well-connected actors are to the parts of the network with the greatest connectivity. Source: CORDIS
Betweenness FP7-	Betweenness FP7-NMP	Betweenness Centrality: Number of shortest paths between *i* and *k* that actor *j* resides on. Betweenness measures the probability that an actor would be along all the possible paths connecting the nodes of the network. Source: CORDIS
Structural Holes FP7-NMP	Structural Holes (Effective Size) FP7-NMP	Structural Hole: "Empty space" between contacts in a university's network. Effective size: Number of non-redundant contacts in a focal actor's network (Burt, 1992). Source: CORDIS
Control Variables	**Indicator**	**Description**
University Size	Number of students	Ordinal variables based on the classification of the QS Ranking: <5,000 = 1; 5,000–12,000 = 2; 12,000–30,000 = 3; >30,000 = 4. Source: Various sources (QS University Rankings, university websites, reports, etc.). Year: Various years.
R&D Expenditure (NUTS 1 and 2)	Gross domestic expenditure on R&D	Total expenditure on R&D carried out by all resident companies, research institutes, universities, government laboratories, etc. in a region as a percentage of GDP. Source: Eurostat, OECD, World Bank, other sources. Year: Various years.
EU Membership	EU membership age	EU membership age: Categorical variables: No Membership = 0; 2013 = 1; 2007 = 2; 2004 = 3; 1995 = 4; 1986 = 5; 1981 = 6; 1973 = 7; Founder (1957) = 8. Source: EU.
Country		Fixed effects/dummy variables
Other variables (Robustness Check)		
Control Variables	**Indicator**	**Description**
Founding Year	Historical age of universities	Ordinal variables based on the universities' founding year (see Geuna, 1998): 1 = New post-war university (institutions established after 1945); 2. Modern university (institutions created between 1900 and 1945); 3. Nineteenth century university (university founded between 1800 and 1900); 4. Old university (organizations founded before 1800). Various sources.

APPENDIX A (Continued)

Econometric Models		
Dependent Variables	**Indicator**	**Description**
R&D Expenditure (NUTS 0)	Gross domestic expenditure on R&D	Total expenditure on R&D carried out by all resident companies, research institutes, university and government laboratories, etc. as a percentage of GDP (EU countries; NUTS 0). Source: Eurostat. Year: Various years.
EU Membership (Dummy variable)	EU membership from/ before 2004	EU membership age: Categorical variables: From 2004 = 0; Before 2004 = 1. Source: EU.