The Journal of Technology Transfer (2021) 46:828–853
https://doi.org/10.1007/s10961-020-09816-3

The European research landscape under the Horizon 2020 Lenses: the interaction between science centers, public institutions, and industry

Marta Ferrer-Serrano[1] · M. Pilar Latorre-Martínez[2] · Lucio Fuentelsaz[1]

Published online: 12 July 2020

Abstract
This research analyses the European landscape of innovation in small and medium-sized enterprises (SMEs). To achieve this objective, data collected from the Horizon 2020 strategy is extracted, which includes 1055 research projects that focus on innovation in SMEs. A complex network analysis is carried out at three levels: (1) at aggregated level by participating European countries, (2) at aggregated level according to the actors of the Triple Helix model, and (3) at disaggregated level according to the individual entities participating in the program. The results allow us to understand the European environment that drives innovation in SMEs. First, this study provides a descriptive overview of the relationships between European countries that favor innovation, and it also describes the positioning of each of them in the joint network. Second, this analysis is able to identify the most relevant agents in the network, the Big Science Centers, and their relationships with industry and public institutions. This study can be used as an analytical tool to improve knowledge transfer in complex ecosystems.

Keywords Innovation · SMEs · Network analysis · Horizon 2020 · Triple Helix model

1 Introduction

The role of collaboration and networking in innovation decision processes has long been debated in academic literature (Bogers et al. 2017; Simonin 1999). Within this literature special focus has been placed on the need for networking between research centers, industry, and public institutions (Farinha et al. 2016; Li et al. 2018), which gives rise to the well-known Triple Helix (TH) model (Etzkowitz and Leydesdorff 1995). While these collaborations are fundamental for any firm, they are critical in the particular case of small and medium-sized

✉ Marta Ferrer-Serrano
martafe@unizar.es

1 Department of Business Management, Facultad de Economía y Empresa, University of Zaragoza, Gran Vía 2, 50005 Zaragoza, Spain

2 Department of Business Management, Facultad de Ciencias Sociales y del Trabajo, University of Zaragoza, Violante de Hungría, 23, 50009 Zaragoza, Spain

enterprises (SMEs) (Dhanaraj and Parkhe 2006) who often lack the resources needed to independently undertake R&D actions (Li et al. 2018; Nordman and Tolstoy 2016).

Recent studies have encouraged specific analysis of business networks with the purpose of examining complex contexts (Latorre et al. 2017; Tsai 2001). Surprisingly, there is little transnational research to date that visualizes the existing collaborations that drive innovation in SMEs based on the agents of the TH model. With this argument in mind, our research question tries to enhance the understanding of the complex relationships that are developed in the European ecosystem. In particular, we are interested in questions such as how research on innovation in SMEs is channeled through networks and which European countries lead innovation projects in SMEs.

Given this research question, this paper has two objectives: (1) to evaluate the research landscape in Europe that promotes innovation in SMEs through analysis of Horizon 2020 strategy funding, and (2) to explore the position of each of the agents making up the TH model in their role as active subjects in research into innovation in SMEs. To achieve this objective, we adopt network analysis to visualize the European landscape in terms of research on innovation in SMEs. To do so, we construct a database that is extracted from the European Horizon 2020 strategy (H2020). We consider all funded research projects falling under the class Innovation in SMEs. This search process resulted in 1055 projects that were funded between 2014 and 2019, amounting to €444,557,465 distributed between 971 private firms (€377,869,420), 399 public institutions (€32,023,509) and 213 BSCs (€37,664,536).

Three types of complex networks will be developed and analyzed: through the first one, we will provide a panoramic scenario of all of the collaborative connections between European countries; the second will enable us to identify collaborative connections that classify agents according to the TH model in an aggregate way; finally, a network-based analysis approach is carried out to better visualize the collaborative connections between European agents of the TH model on an individualized basis.

This work constitutes a first step to provide a reference framework to visualize the collaborative networks in Europe that drive innovation in SMEs using the TH model as a tool. Furthermore, the analysis of centrality that underlines network analysis will allow us to identify the importance of each agent in the network and their proximity to one another. Consequently, we will first identify the degree of connectivity between European countries. Our main conclusion is that the location in the network does not have a linear relation with the funding received. Second, although most of those participating in innovation activities in SMEs are private sector companies, the most relevant drivers in the European network are BSCs. Therefore, this exploratory study contributes to the understanding of the structure and configuration of the European network of innovation in SMEs.

The rest of the paper is organized as follows: Sect. 2 presents a review of the academic literature. Section 3 describes the method that we adopted to carry out this research. In this section, we provide information about the data collection and the measures used in the network study. Section 4 presents the results of the empirical analysis. Finally, Sect. 5 discusses and concludes the paper.

2 Theoretical background

The relevance of knowledge transfer has been object of a deep discussion in recent decades (Cunningham and O'Reilly 2018; Easterby-Smith et al. 2008; Inkpen and Tsang 2005; Simonin 1999). Specifically, the term refers to the process through which one business unit, group, department, or division is affected by the experience of another (Argote and Ingram 2000; Darroch 2005; Link and Sarala 2019). Although this process can occur within a particular firm, there is an increasing amount of literature showing how knowledge from external sources can bring distinctive value to a company (Inkpen and Tsang 2005) and generate competitive advantages (Easterby-Smith et al. 2008; Pérez-Nordtvedt et al. 2008; Szulanski 1996). Scholars have argued that knowledge transfer may have positive effects both for the broadcasting and the receiving company (Argote et al. 1990; Baum and Ingram 2002). New knowledge, especially when it is external to the firm, can be an important stimulus for change and for organizational and social improvement (Baglieri et al. 2018; Inkpen and Tsang 2005), thus becoming an engine of economic change (Coccia 2019, Kotabe et al. 2003; Nepelski and Piroli 2018).

Among the drivers of knowledge transfer, the relationships established between three major social actors, namely science centers, industry, and public institutions have received increasing attention in the literature (Farinha et al. 2016) due to their contribution to societal progress and growth. The main concept that emerges from this debate is the TH model, which describes the importance of links between the above actors. These networked relationships constitute a key element in the knowledge-based economy (Etzkowitz and Leydesdorff 1995). The TH model leads to a better understanding of a complex process that requires the involvement of numerous agents.

In the specific case of universities as science centers, their mission has recently evolved to include the increasing demand to take the needs of society more directly into account. Universities are often asked how they contribute to economic growth and entrepreneurial activity in addition to their traditional research through teaching and publication (Baglieri et al. 2018). The concept of entrepreneurial universities arises in different academic forums (Guerrero et al. 2016; Ranga et al. 2003) and is linked to the new role that they have adopted (Gunasekara 2006; Hervas-Oliver et al. 2011). Ranga et al. (2008) argue that the presence of an entrepreneurial university offers significant competitive advantages to the region where they are established and paves the way for the creation and consolidation of knowledge regions. Research technology organizations (defined as organizations whose main business is R&D to enhance the innovative performance of their customers) constitute the second pillar of science centers. They have also reoriented their activity to strengthen their networks with private companies and the literature suggests that they should adopt a leading role in R&D collaboration (Albors-Garrigós et al. 2014).

The two types of institutions share similar objectives, and thus, closer relationships should be created between research technology organizations and universities. We integrate them under the label of BSCs. Huang et al. (2010) suggest that firms that collaborate with universities and research institutions are more likely to be R&D performers, while firms that source information from suppliers and competitors have a higher probability of innovating through non-R&D activities. Farinha et al. (2016) point out that networks generated between academia and industry enable a strong contribution to improving regional competitiveness through the development of new projects and new market technologies. As a consequence, we consider that the new enhanced mission of BSCs will have a relevant position in the ecosystem of a region through the promotion of synergies between the agents of the TH model.

The relationship between firm innovation and collaborative networks has been analyzed in the literature (Dhanaraj and Parkhe 2006; Swan et al. 1999). Network members are exposed to the acquisition and absorption of different, potentially valuable sets of knowledge. Therefore, knowledge transfer, as an antecedent of firm innovation, arises as a consequence of the interaction and spillovers that take place between different organizations

(Etzkowitz and Leydesdorff 1995; Farinha et al. 2016). According to Inkpen and Tsang (2005), there are two mechanisms that operate at this level: (1) a network that can facilitate learning through knowledge transfer from one firm to another, and (2) a network that can become the locus of new knowledge creation. So there is evidence that a company significantly improves its innovative capabilities by taking advantage of others' skills through knowledge transfer.

Through the analysis of networks it is possible to model the relationships or interactions between a set of social entities, such as people, groups, or organizations. Therefore, the analysis of the structure of networks aims to understand the behavior of the systems that are generated. Thanks to this type of analysis, the main actors in the network can be identified. Complementarily, centrality indicators are widely researched in knowledge areas such as physics, computer science, and business. Their contributions to science are demonstrated in many papers published in high impact journals (Barrie et al. 2019; Huggins et al. 2019; Latorre et al. 2017). Actors with a "more central position" (greater centrality) have easier and faster access to other actors in the network (useful for accessing resources such as information) and a greater ability to exercise control over the flow between them. From a holistic perspective, this type of method makes it possible to analyze complex ecosystems composed of numerous subjects, visualize them, and identify the links between them. Furthermore, if centrality metrics are analyzed, all the above information is complemented with data on the positions, relevance, proximity, and importance of each individual in complex structures.

Network analysis allows, among other things, the outlining of implications and recommendations for management. It enables the identification of weaknesses and strengths of the ecosystems, as it is able to draw appropriate lines of action. In addition, this type of study allows us to know contexts that otherwise would not be possible given the multitude of interacting actors. On the other hand, the study of complex networks allows us to identify areas of high interest for collaboration, competitors, or example agents, among other aspects. In other words, special attention should be paid to the centrality and cohesion of networks that form complex ecosystems, because these indicators provide valuable information on expected future results. For example, Nordman and Melén (2008) and Xu et al. (2019) observe that networks can provide access to extended resource bases and therefore serve as platforms for business development in relationships with foreign markets. However, a successful transfer phenomenon that helps to achieve greater business innovation is complicated, because different subjects are interacting at the same time in a territory that is influenced by external features (Coccia and Wang 2016; Rammer et al. 2020; Szulanski 1996) responding to technologically and economically complex environments (Fernández-Sastre and Montalvo-Quizhpi 2019; Teece 2010).

Consequently, there are some studies that analyze the networks into which organizations are integrated to explain firm behavior (Latorre et al. 2017; Tsai 2001). It has been argued that the network occupied by actors, defined by the nature of their relationships, interactions, and linkages, can be at least as important as the geographic space in which the actors are located and interact (Huggins et al. 2012). Moreover, firms with greater networking capabilities are more likely to benefit from these links. This implies that there is a significant "flow" of knowledge from the science-base to "end-user" firms via private sector consultancies, research organizations, or universities (Barge-Gil et al. 2011; Tether and Tajar 2008). The success of inter-organizational relationships relies on having in-depth knowledge of their characteristics. For this reason, analyses that do not consider the interactions between different agents in a given network are incomplete and may derive misleading conclusions regarding the knowledge transfer process. A better understanding of the complex networks that are established between the different actors can be considered as a precursor to knowledge transfer. It is true that our research is limited to the first phase of this process, but it is a necessary condition for improving our understanding of the innovation process as a whole.

From the above arguments, we could conclude that network-based analysis has become increasingly important. Nevertheless, the results of previous research should be analyzed with care, because most of the studies are performed in technologically intensive sectors (Lamine et al. 2018) and in sectors where there is strong competition (Huenteler et al. 2016). These are sectors where large companies usually operate, the struggle for survival is evident, and having resources allocated to R&D is crucial (Cano-Kollmann et al. 2016; Gupta and Govindarajan 2000). However, SMEs do not have the same capacity to carry out activities such as research and innovation; thus, networks are particularly important for them (Brunswicker and Vanhaverbeke 2015). They often lack tangible resources and are therefore heavily dependent on intangible resources that are accessed outside their boundaries. Since SMEs are highly restricted in developing new knowledge on their own, complementing their own technology resources with external knowledge widens their opportunities to successfully transfer R&D results into products and processes. External R&D allows SMEs to limit their own risk, have a better control of costs or R&D, and a specialization in those technology competences for which they have the best resources (Rammer et al. 2009). These arguments suggest that connectivity in network environments should be considered a prerequisite for innovation, because it provides knowledge and access to resources that would otherwise not be available to individual companies (Nordman and Tolstoy 2016), which is especially valuable for SMEs.

For example, Zeng et al. (2010) found a significant positive relationship between networks and innovation performance in their study of 137 Chinese manufacturing SMEs. Studies have also revealed that SMEs can effectively overcome size problems through access to network resources by creating, transferring, and combining resources, enabling them to discover opportunities without the need of costly research (Crick and Spence 2005; Nordman and Melén 2008). Similarly, de Jong and Vermeulen (2006) argue that small firms can gain competitive advantages by cultivating specific business relationships as a means of developing new knowledge, which, in turn, can lead to new innovation outcomes. Hervas-Oliver et al. (2011) conclude that R&D innovators accounted for the majority of the external resources of knowledge, and the non-R&D innovators, usually SMEs, show very low percentages of external cooperation, although they are much more active than the non-innovative firms. Li et al. (2018) analyze a sample of US SMEs and provide evidence of the importance of the local dimension of the TH interactions in transferring knowledge among innovation actors who share a nearby location. Barge-Gil (2010) found that smaller, less R&D-intensive collaborating firms are more frequent cooperation-based innovators, while large, R&D intensive firms are usually peripheral cooperators.

3 Methodology

In order to clarify the study design process, Fig. 1 shows the different stages that have been carried out. Particularly, three major steps: data collection, construction of a large database and finally, generation and analysis of complex networks and indicators of centrality. Subsequently, the results are obtained and interpreted, as well as the implications and conclusions of the study are formulated.

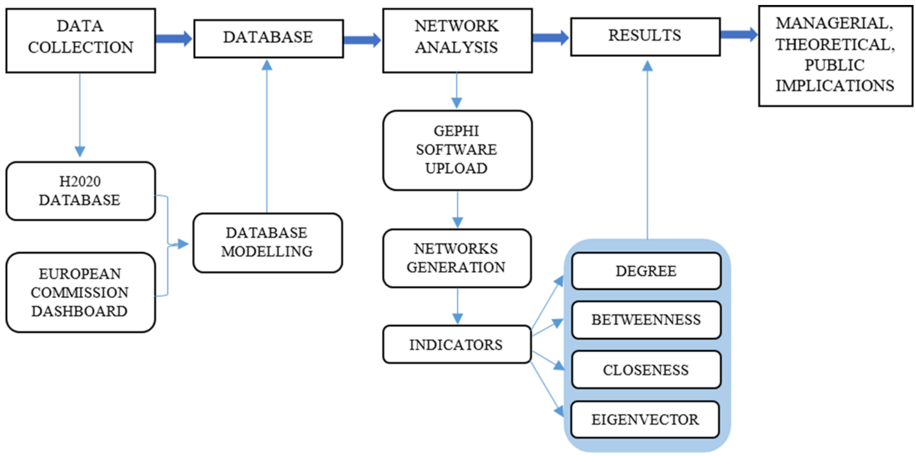

Fig. 1 Study design process

3.1 Data collection

The data collection has been carried out based on the information provided by the European Commission's website in its section on the H2020 strategy, which is the EU's largest research and innovation program to date, with funding of almost 80 billion euros over 7 years (2014–2020). In addition to funding the development of science and technology, one of the main objectives of the H2020 program is to foster international collaboration between science organizations and private companies, both large and small. The main motivation for this strategy is that innovation is often the result of the interaction and cooperative efforts of different organizations dedicated to the achievement of a common goal. To participate in the programs, countries must belong to the EU or to the list of associated countries. In our analysis, to keep the focus on a limited geographical space—we considered all those research projects and collaborations between European countries, and we did not consider collaborations outside Europe.

The H2020 strategy is based on three main pillars: excellent science, industrial leadership, and social challenges. These pillars are structured around 35 categories that include leading research topics. In particular, we considered all funded research projects that fall under the subcategory defined as innovation in SMEs, which belongs to the second pillar (industrial leadership). This search process resulted in 1055 funded projects between 2014 and 2019.[1]

The total funding for the category of innovation in SMEs amounts to 444,557,465 euros. The average grant per project is 424,225 euros, and the average grant per individual participant is 249,474 euros. Given that we did not consider collaborations with countries outside Europe, the total amount considered in our study amounts to 413,423,526 euros, and the average grant per participating country is 10,600,603 euros. The database includes a total of 1583 individual participating entities and 39 European

[1] Data has been extracted from: https://cordis.europa.eu/projects/es.

countries. Of the total number of research projects that promote innovation in SMEs, 519 collaborative links are detected between the participating institutions.

Table 1 summarizes the data per country. As can be seen in Table 1, more than half of the amount financed by H2020 is concentrated in five countries—that is, Spain, France, Germany, Italy, and the Netherlands—, while 47% of the remaining funding is distributed among 34 countries. In addition, the last column relates the resources obtained by each country and its GDP. A higher value of this ratio would indicate that the country participates in H2020 more than expected according to its macroeconomic indicators, and vice versa. Among the biggest countries, Spain obtains twice as many resources as it would expect according to its economic weight, while Germany and, above all, United Kingdom, are underrepresented in H2020. Among the small and medium economies, the share of the Nordic countries, Estonia, Serbia and Armenia is much greater than expected.

The variables that are analyzed in our study can be classified into four main groups: those relating to subsidy (by country, organization, project, and type of agent), geographical location (at country level), the number of collaborations (between countries) and the type of agent (public institutions, industry, or science centers). Several indicators of centrality will be used in our empirical study, which are very useful in complex networking techniques. These measures are developed in the following section.

3.2 Network analysis and centrality measurements

As said in previous sections, knowledge transfer, as an antecedent of firm innovation, arises as a consequence of the interaction and spillovers that take place between different organizations. Increasingly, this process is viewed as a systemic undertaking, i.e., firms no longer innovate in isolation but through a complex set of interactions with external actors. Therefore, external knowledge networks are potentially an important aspect of the innovation process. It is through these pipelines that firms procure knowledge that they do not, or cannot, generate internally based on their own capabilities. In other words, knowledge transfer takes place trough knowledge networks and spill overs between firms (and other agents that interact in the innovation ecosystem).

With this in mind, this section shows the relevance of the analysis of complex networks, as well as the theoretical description of the centrality measures used in the paper. First, we explain what a network is and what its advantages are. Next, we describe the measures used to analyze the networks.

Network analysis is an approach that uses different measures to describe and link the relationship that exist between entities. The advantages of using network analysis in our research are twofold: (1) it allows a better understanding of how European research on innovation in SMEs works; and (2) it can be used as a resource allowing individual entities to study their own relationships and make comparisons with other agents, providing value information that can be useful in the adoption of future decisions.

In the first place, we define the types of networks that we examine in this work. Let $G=(V, E)$; be a graph in which V represents the set of institutions or entities (we use the term nodes, institution and entities with the same meaning) participating in H2020 in our field and E represents the set of links or collaborations between them. Let $(v_i, v_j) \in E$, with $v_i, v_j \in V$, be an edge in G that represents any kind of relationship between institutions v_i and v_j.

In this document we only focus on directed graphs, since we assume that the relations are directional, that is, if there is $(v_i, v_j) \in E$ it does not imply that $(v_j, v_i) \in E$ does

Table 1 Participating European countries and grants financed by the H2020 strategy (2014–2019)

Country	Grant (euro)	Grant (%)	GDP (%)	Grant/GDP	Country	Grant (euro)	Grant (%)	GDP (%)	Grant/GDP
Spain	56,748,444	13.7	6.77	2.02	Serbia	2,334,513	0.6	0.24	2.48
France	52,065,714	12.6	13.26	0.95	Belgium	1,799,941	0.5	2.59	0.19
Germany	43,633,079	10.6	18.84	0.56	Croatia	1,604,770	0.4	0.29	1.38
Italy	34,832,328	8.4	9.95	0.84	Romania	1,395,996	0.4	1.14	0.35
Netherlands	30,615,484	7.4	4.36	1.70	Turkey	1,223,427	0.3	3.68	0.08
Sweden	27,269,178	6.6	2.66	2.49	Czechia	1,100,568	0.3	1.17	0.26
Norway	22,393,585	5.4	2.07	2.60	Armenia	752,800	0.2	0.06	3.37
Denmark	21,185,566	5.1	1.70	3.00	Slovenia	606,009	0.2	0.26	0.78
Finland	19,650,288	4.8	1.32	3.63	Cyprus	527,273	0.1	0.12	0.84
United Kingdom	17,788,961	4.3	13.63	0.32	Lithuania	513,594	0.1	0.26	0.39
Austria	14,963,226	3.6	2.17	1.66	Slovakia	504,765	0.1	0.51	0.20
Ireland	12,460,878	3.0	1.83	1.64	Bulgaria	436,804	0.1	0.32	0.32
Poland	10,844,936	2.6	2.80	0.93	Latvia	357,053	0.1	0.16	0.61
Switzerland	9,386,214	2.3	3.37	0.68	Malta	143,338	0.0	0.07	0.00
Portugal	6,486,982	1.6	1.15	1.39	Ukraine	100,000	0.0	0.62	0.00
Iceland	5,774,105	1.4	0.12	11.30	Montenegro	43,994	0.0	0.03	0.00
Greece	4,049,466	1.0	1.04	0.96	North Macedonia	23,713	0.0	0.06	0.00
Estonia	3,564,756	0.9	0.15	6.13	Moldova	14,225	0.0	0.05	0.00
Luxembourg	3,312,144	0.8	0.34	2.36	Bosnia Herzegovina	5,689	0.0	0.09	0.00
Hungary	2,909,721	0.7	0.75	0.93					

not necessarily exist. Therefore, the graph G generated by the network is directed. This approach allows us to analyze this type of network as a tool to interpret and improve the performance of network entities, which has direct implications from a management perspective.

Centrality metrics are necessary to shed light on the importance of an entity's position in the network. These allow us to understand behaviors and properties in a network. As said previously, actors with a greater centrality have easier and faster access to other actors in the network and a greater ability to exercise control over the flow between them. Some centrality metrics are explained below.

Degree centrality (Freeman 1977), identifies the number of links a node has and shows how well an institution is connected in terms of direct links. Although it perfectly denotes the degree of connection of an institution, it does not reflect the position it occupies in relation to the network. Its theoretical representation is:

$$DC^{v_i} = \frac{d\left(v_i\right)}{|V| - 1}$$

where $d\,(v_i)$ denotes the degree of centrality of the node v_i in the network.

Closeness centrality (Beauchamp 1965), denotes how close a given node is to any other node in the network. This could be interpreted as an agent's ability to connect with other agents. It emphasizes the distance of one actor from others in the network by focusing on the geodetic distance of each actor from all others. Mathematically, it is represented as follows:

$$CC^{v_i} = \frac{|V| - 1}{\sum_{v_i \neq v_j} sp\left(v_i, v_i\right)}$$

where $sp\,(v_i, v_i)$ is the number of connections on the shortest path between the v_i and v_j node.

Betweenness centrality (Freeman 1977), measures the frequency with which a given node appears on the shortest path between any two nodes in the network. This metric is used to measure the relevance of an agent in the network and to explore the influence these agents may have on a possible mediation to initiate a new relationship. Let $np\,(v_j, v_k)$ be the number of routes between $v_j \in V$ and $v_k \in V$. Then, we obtain the centrality of the node v_i in terms of connecting v_j and v_k as a ratio. Formally:

$$BC^{v_i} = \sum_{v_j \neq v_k \neq v_i} \frac{\frac{np_{v_i}\left(v_j, v_k\right)}{np\left(v_j, v_k\right)}}{\frac{1}{2}(|V| - 1)(|V| - 2)}$$

Eigenvector centrality (Bonacich 1987), represents the importance of a node in the network. It is based on the fact that the centrality of a particular node depends on how central its neighbors are. It is a more elaborate version of the degree centrality by assuming that not all connections are of equal importance. Let $EC\,(G)$ be the centrality of a vector associated with a network G; the crux is that the centrality of a node is proportional to the sum of the centrality of its neighbors. Its representation is:

$$\lambda \cdot EC^{v_i}(G) = \sum_{v_j} g_{ij} EC^{v_j}(G)$$

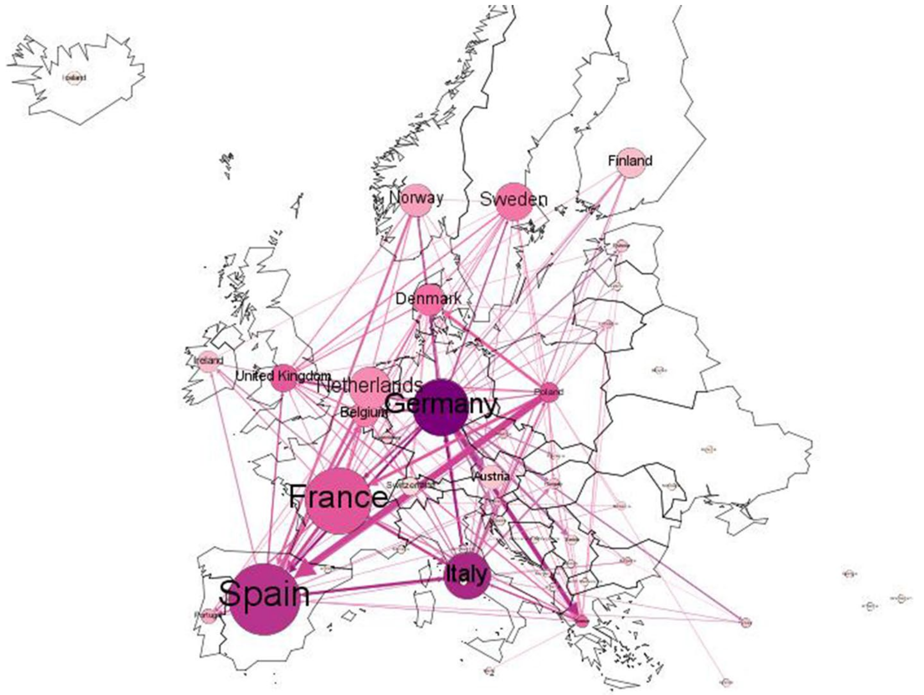

Fig. 2 Network of the EU countries who participate in Innovation in SMEs (2014–2019). Node size is related to the perceived amount. Node color is associated with the degree centrality coefficient. The thickness of the link represents the sum of the number of collaborations. The color of the link represents the average of the connected relationship (Color figure online)

in which g_{ij} takes the value 1 if $(v_i, v_j) \in E$ and 0 otherwise and k is a proportional factor.

4 Results

Three different scenarios have been analyzed. The first scenario gives visibility to the European network by participating countries. The second scenario shows the knowledge transfer between the three main agents of the TH model. Finally, in the third scenario the entire network is analyzed by disaggregating the data by participating entities in the whole of Europe. We consider these scenarios because, on the one hand, they provide a European descriptive panorama in which we visualize the collaborative capacity in innovation of SMEs by countries; while on the other hand, the individual analysis allows us to identify the most important agents in a complex context in which the capacity for connection is fundamental.

Figure 2 presents a graphic representation of the network generated on the European stage. The size of the nodes represents the amount of finance granted by the H2020 strategy to projects belonging to the field Innovation in SMEs (the greater the size of the nodes, the higher the amount of funding grants). The color of the nodes is related to the degree centrality coefficient, which allows us to perceive the degree of connection of institutions: nodes with higher centrality are darker. The arrow that measures the links is the sum of the number of collaborations between the two countries in the total of the financed projects, which are colored according to the average of the connected relationship. It is deduced from the network that the countries that receive the most funds to promote innovation in SMEs are Spain, France, and Germany.

The degree of centrality of each of the countries differs with respect to the financial amount perceived. In this case, the node with the highest degree of centrality is Germany as the country that collaborates most with the other countries in industrial innovation projects, followed by Italy and Spain. Another dimension that this representation allows us to analyze are the collaborative links that exist in Europe. In this sense, the countries that have developed the greatest number of collaborations are Poland and Spain. In addition, it is possible to contemplate that the mesh has a greater density in the European center than in the peripheries. As the countries move away from the old continent, the network seems to become more fragile.

The results of the centrality metrics are shown in Table 2, which provides some interesting findings. In this table, we have included all these European countries that have participated on at least one occasion in the program. According to the degree centrality, Germany, followed by Italy and Spain, occupy the most relevant positions. This means that they are more frequently related to the other countries. Focusing on the closeness centrality, eigenvector centrality and betweenness centrality, the results lead us to similar conclusions. Germany stands out in each of the measures. Other nodes with high values of our key indicators are Italy, Spain, the United Kingdom, Poland, and Denmark. This suggest that these countries have the shortest average distance in comparison with the rest of the network nodes (closeness centrality). It is also more likely that they are present in the way of connection between two nodes (betweenness centrality).

This metric lets us interpret how good the countries are in terms of being intermediaries in research collaborations. As explained in the previous section, the eigenvector centrality represents the importance of a node in a network. In this case, Germany, Spain, Italy, Poland, the United Kingdom, France, and Denmark represent the countries with the greatest distinction in the network. This general picture reveals several interesting aspects. First, we can conclude that receiving a lot of funding from H2020 is not as important as having a good position in the network in terms of centrality. Second, this is a complex and apparently well-cohesive network, so its possible fragmentation seems complicated. This fact at least applies to the center of the continent, where most of the interconnections are concentrated. Consequently, this high cohesive density will allow the flow of innovative knowledge to work efficiently between countries where network fragmentation seems difficult.

To build the second scenario, which consists of the generation of an aggregated complex network that identifies the connections between the three agents of the TH model, it was necessary to classify each entity according to their industrial activities, particularly by individually consulting its corporate information. The criterion that we followed was to consider as public institutions those entities that belonged to the government and those whose financing from public sources exceeds 50%. Therefore, all educational institutions and science centers were included in the BSC sector due to the new entrepreneurial role that they have assumed. Finally, to differentiate private sector companies and science centers into different categories, the activities, competencies, products, and services offered by each of them were consulted. In the case of the science centers, their main activity consists of carrying out R&D tasks. In contrast, the competences covered more fields in private sector companies, such as consultancy, sale of products or employee training, among others. In particular, 971 private firms participated in research projects related to innovation

Table 2 Results obtained using centrality measurements (2014–2019)

Country	Betweenness centrality[a]	Closeness centrality[b]	Degree centrality[a]	Eigenvector centrality[b]
Austria	3	0.516	5	0.242
Belgium	0	0.571	15	0.602
Bosnia Herzegovina	0	0.368	2	0.046
Bulgaria	0	0.508	5	0.298
Croatia	0	0.471	2	0.154
Cyprus	0	0.410	1	0.067
Czechia	0	0.508	7	0.305
Denmark	6	0.653	17	0.707
Estonia	0	0.516	5	0.299
Finland	0	0.525	6	0.422
France	2	0.627	21	0.750
Germany	26	0.842	36	1.000
Greece	8	0.627	19	0.687
Hungary	0	0.533	6	0.408
Ireland	0	0.516	6	0.411
Italy	8	0.727	29	0.873
Latvia	0	0.464	1	0.082
Lithuania	1	0.552	8	0.380
Luxembourg	0	0.508	5	0.262
Malta	0	0.390	1	0.056
Netherlands	3	0.582	13	0.551
Norway	0	0.552	10	0.535
Poland	9	0.681	21	0.821
Portugal	0	0.552	9	0.508
Romania	0	0.451	3	0.202
Serbia	0	0.478	2	0.139
Slovakia	0	0.464	1	0.082
Slovenia	3	0.525	6	0.300
Spain	7	0.727	27	0.911
Sweden	1	0.604	16	0.695
Switzerland	0	0.416	2	0.103
Turkey	0	0.500	5	0.253
Ukraine	0	0	0	0
United Kingdom	3	0.653	20	0.811

[a]Betweenness and degree centrality goes from 0 to infinite

[b] Closeness and eigenvector centrality goes from 0 to 1

in SMEs (377,869,420 euros), 399 public institutions (32,023,509 euros), and 213 BSCs (37,664,536 euros).

Figure 3 shows, through a histogram, the relationships created for the generation of the graph and the weight of these collaborations in terms of the monetary amount financed by H2020. The lack of parallelism between the number of connections and the perceived quantity is confirmed. This means that the values obtained both in number of connections

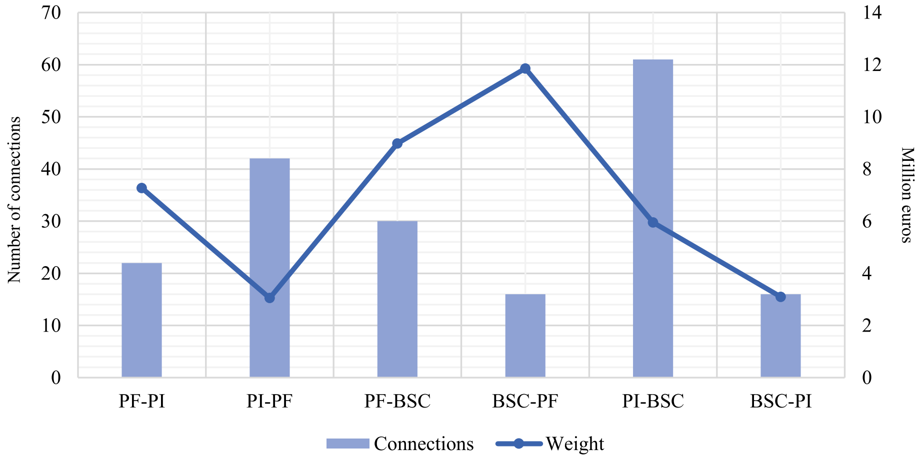

Fig. 3 Histogram with the connections and weight data represented in TH aggregated network (2014–2019). Connections refers to the total number of links between agents. Weight represents the total amount assigned by the H2020 strategy to the different actors (millions). The first agent of the relations occupies a leadership role in the projects and the second agent occupies a role of collaborator or executor. Acronyms: PF = Private Firms; BSC = Big Science Centers; PI = Public Institutions

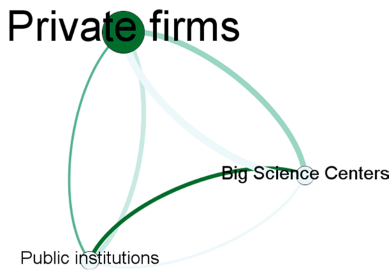

Fig. 4 Aggregate network of the EU participants and collaborations under the Innovation in SMEs projects according to the TH model (2014–2019). Node size and color are related to the perceived amount. The thickness of the links illustrates the grants financed. The color of the links represents the number of connections. The directions of the links refer to their role as leaders (origin) or executers (destiny) (Color figure online)

and in perceived resources are not necessarily coincidental and depend on the role adopted by the different actors. For example, when private companies are project leaders and public institutions adopt a collaborating role (see the first bar in Fig. 3), the number of connections is lower and the volume of resources obtained is much greater than if the role of the agents is exchanged. This fact also occurs in the pair of actors composed of private companies and BSCs.

Figure 4 complements the information provided by Fig. 3 by representing the connections generated between the three agents of the model. The size of the nodes illustrates the total amount of resources granted to each of the sectors (private firms represent 84.43% of the total amount of grants, while public institutions represent 7.16% and BSCs 8.42%). The origin of the links is represented by the coordinating entities of the research projects (leading role) and the destination by the collaborating entities (executer role). The links are colored according to the number of connections between agents (the color is darker when the number of collaborations is greater).

This second aggregated ecosystem enables us to identify, in a descriptive way, some interesting aspects. In the case of the BSCs, the number of collaborations is very limited in their role as project leader. However, their role as executor is much more important, both, in their relationship with private firms and with public institutions. The opposite can be said about public institutions, who often act as project leaders but do not execute the projects. In contrast, this analysis reveals that the collaborations between BSCs as coordinators and private companies as executor are beneficiaries of a greater number of subsidies than the other relationships. In addition, the number of relationships in which private firms have the coordinating role is higher than in those in which the BSCs have the coordinating role, but the funding obtained is much lower.

Table 3 complements the information provided in Fig. 4 by summarizing the 10 institutions that have perceived the greatest funding in each group according to the distinction made by the TH model. The five most financed institutions correspond to private sector companies (e.g., Norway Health Tech and Fundingbox Accelerator Sp Zoo standout), while the first public institution ranks 15th.

Finally, with the aim of analyzing the structure of relationships in greater depth, Figs. 5 and 6 consider all of the individual companies that collaborate in the H2020 strategy—they depict the same network but with a different software layout. The two representations locate the most interconnected nodes in the center of the network, while the nodes of minor importance extend towards the outer region. The color of the nodes represents the group in which they are classified according to the TH model (i.e., private sector companies, public sector institutions, and BSC). In Fig. 5, the node's size is determined by grant disposal. In both representations, the thickness of the links is measured through the total amount of money financed by the H2020 strategy, the direction of the connection between the coordinating entity of the project and the other collaborators, and finally the links are painted the same color as the node of origin. In Fig. 6, the node's size is determined by the degree of centrality.

The comparison of the two images allows us to derive some meaningful conclusions. Although private companies obtain a great amount of resources, their connectivity is low compared with BSCs (green color in Figs. 5, 6). They manage many less funds but reach a high connectivity in the complex entire network. In addition, the position of private sector companies (purple color in Figs. 5, 6) is more moderate, in spite of their large participation in projects about innovation in SMEs and their high involvement in raising funds for their development. Finally, public institutions (orange color in Figs. 5, 6) do not occupy central positions in the network and have bad cohesiveness with the other participating entities. We can derive from them that the entities that have received the greatest economic funding, mainly private sector companies, do not necessarily have a good connectivity capacity with the other nodes.

Table 4 summarizes the results extracted from the centrality analysis carried out by breaking down the entities and classifying them according to the actors of the TH model. Specifically, the top 10 values of each measure are presented. However, the total number of companies included in Table 4 is only 20 because most of the companies rank similarly in the top 10 in several indexes. Attending to the distribution of the entities with greater values with respect to the centrality indicators, we identify that 11 entities are BSCs and four are private sector companies. The institutions of the public sector do not have high significant values in relation to any of the centrality measures analyzed.

Table 3 Top 10 granted institutions according to every TH model actor (2014–2019)

Rank	Institutions	Country	Agent[a]	Grant (euros)
Group 1				
1	Norway Health Tech	Norway	PF	7,349,069
2	Fundingbox Accelerator Sp Zoo	Poland	PF	4,611,144
3	Pole Solutions Communicantes Securisees	France	PF	3,909,313
4	Combigene Ab	Sweden	PF	3,361,348
5	Cyberforum Ev	Germany	PF	3,291,419
6	Minoryx Therapeutics S.L.	Spain	PF	3,106,250
7	Meta Group Srl	Italy	PF	2,860,625
8	Tla Targeted Immunotherapies Ab	Sweden	PF	2,695,000
9	Avantium Chemicals Bv	Netherlands	PF	2,499,999
10	Bioaxial Sas	France	PF	2,499,999
Group 2				
1	Stichting Centre Of Expertise Watertechnologie	Netherlands	BSC	3,182,781
2	Steinbeis 2i Gmbh	Germany	BSC	2,830,984
3	Biosense Institute	Serbia	BSC	1,594,500
4	Fundacion Corporacion Tecnologica De Andalucia	Spain	BSC	1,371,608
5	Foundation For Research And Technology Hellas	Greece	BSC	1,077,708
6	Aerospace Valley	France	BSC	1,053,568
7	Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.	Germany	BSC	1,004,206
8	Bayern Innovativ—Bayerische Gesellschaft Fur Innovation Und Wissenstransfer Mbh	Germany	BSC	961,150
9	Fundacja Partnerstwa Technologicznego Technology Partners	Poland	BSC	768,213
10	Stichting Wageningen Research	Netherlands	BSC	692,878
Group 3				
1	Eurice European Research And Project Office Gmbh	Germany	PI	1,333,250
2	Paris Region Entreprises	France	PI	1,232,531
3	Kamer Van Koophandel	Netherlands	PI	1,182,310
4	Instituto De Fomento De La Region De Murcia	Spain	PI	1,073,516

Table 3 (continued)

Rank	Institutions	Country	Agent[a]	Grant (euros)
5	Institut De La Propriete Intellectuelle Luxembourg	Luxembourg	PI	1,044,316
6	Agenzia Per La Promozione Della Ricerca Europea	Italy	PI	835,104
7	Ministerie Van Economische Zaken En Klimaat	Netherlands	PI	809,880
8	Agencia Per A La Competitivitat De La Empresa	Spain	PI	634,337
9	Agenzia Nazionale Per Le Nuove Tecnologie, L'energia E Lo Sviluppo Economico Sostenibile	Italy	PI	627,810
10	Vlaamse Gewest	Belgium	PI	581,625

[a]Acronyms: *PF* private firms; *BSC* big science centers; *PI* public institutions

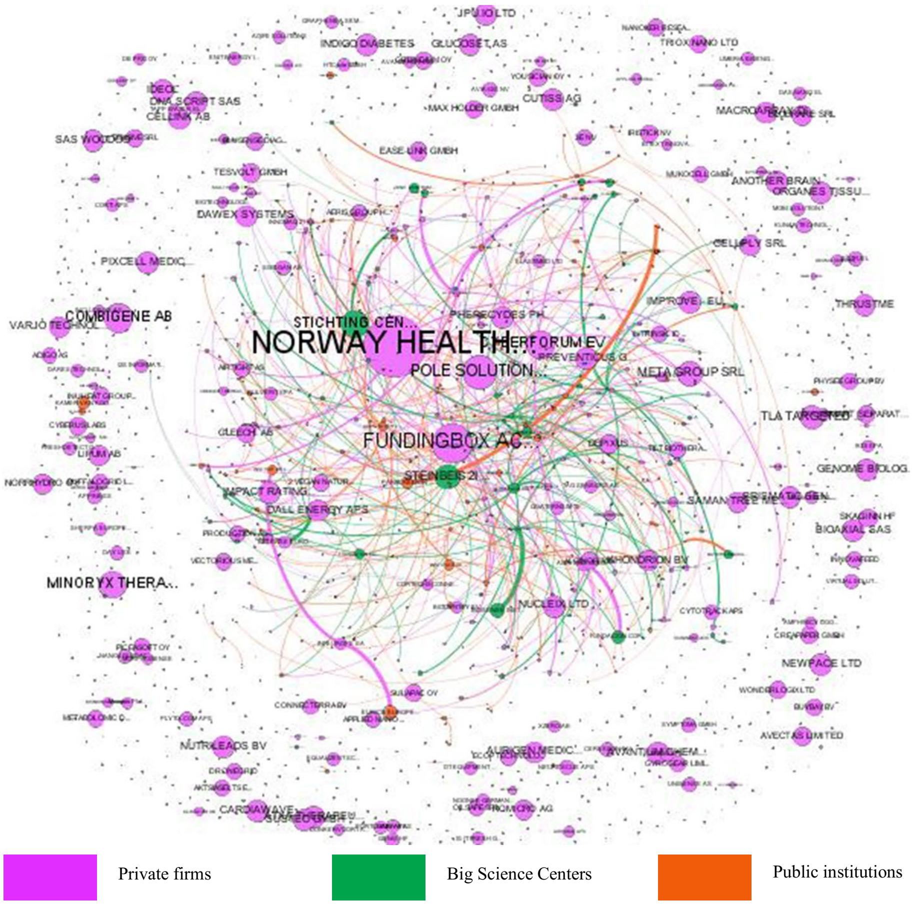

Fig. 5 Network of the EU participants and collaborations under the Innovation in SMEs projects according to the TH model (total amount of grant layout) (2014–2019). The size of the node is related to the perceived amount. The color of the node refers to the TH kind of agent. The thickness of the link illustrates the grants financed. The color of the link represents the origin of the collaboration (Color figure online)

If we pay attention to the degree centrality, we see how the BSCs have values above the average; for example, Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.v., Steinbeis 2i GmbH, or United Kingdom Research and Innovation, with values of 21, 19, and 17, respectively. The entity most central to this measure is a private sector company, Fundingbox Accelerator Sp. z o.o (28). These nodes, attending to the theoretical definition of the measure are the ones that a priori have a greater degree of connectivity.

However, as stated above, this measure is not enough. The measure of closeness centrality provides interesting results. Because its values are normalized [0, 1], the entities with values closer to 1 will represent those nodes that have less mean distance compared to any other in the network and, therefore, more potential to create future collaborations with other nodes. United Kingdom Research and Innovation (0.944), Bwcon GmbH (0.933), and Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.v. (0.852) have greater closeness centrality and they all belong to the BSCs sector.

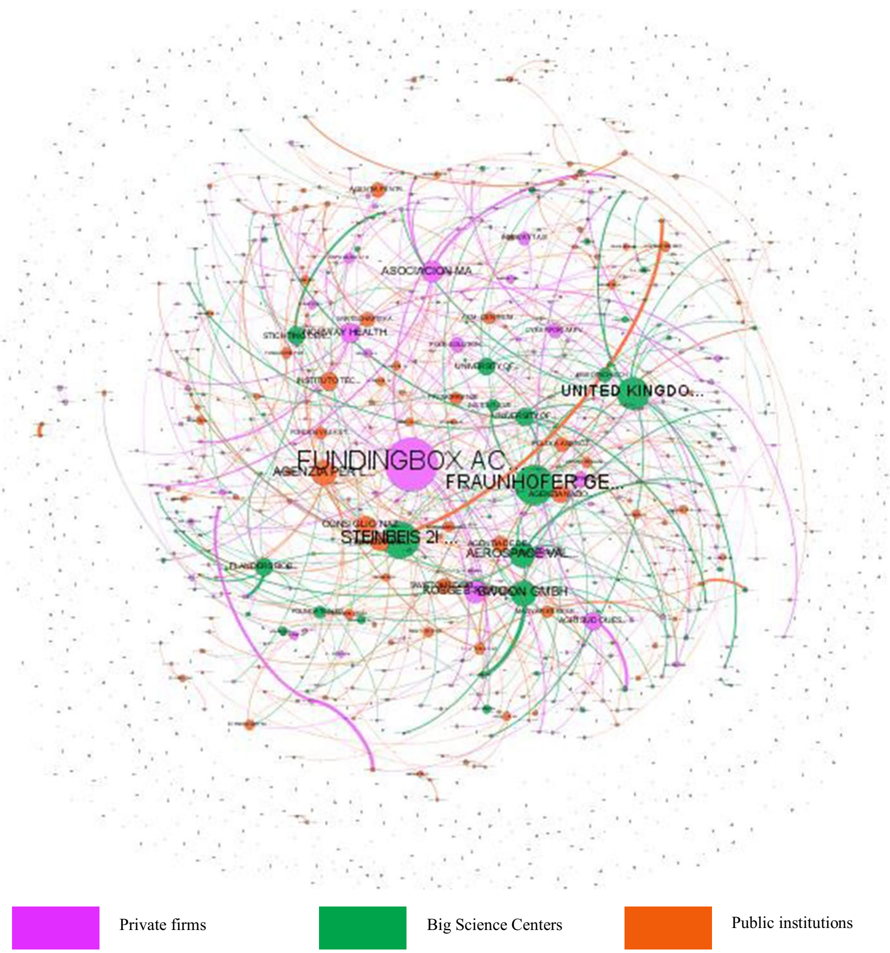

Fig. 6 Network of the EU participants and collaborations under the Innovation in SMEs projects according to the TH model (degree centrality layout) (2014–2019). The size of the node is related to the degree centrality. The color of the node refers to the TH kind of agent. The thickness of the link illustrates the grants financed. The color of the link represents the origin of the collaboration (Color figure online)

One of these nodes also stands out in the measure of betweenness centrality, which is Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.v. Meanwhile, Steinbeis 2i GmbH, Fundingbox Accelerator Sp. z o.o, and Tillväxtverket also stand out. This reveals the importance of the agents because it shows the possibility of intervening and initiating a possible mediation in a new collaboration. Once again, the relevance of the BSCs in the network is verified. Finally, the eigenvector centrality [0, 1], shows how these three science centers that have stood out in the previous measures of centrality, are the most relevant nodes in the network, which are Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.v., Steinbeis 2i GmbH and Fundingbox Accelerator Sp. z o.o.

Table 4 Centrality results from the network analysis among every entity

Firm	Sector[a]	Country	Betweenness centrality[b]	Betweenness rank	Closeness centrality[c]	Closeness rank	Degree centrality[b]	Degree rank	Eigenvector centrality[c]	Eigenvector rank
Aerospace Valley	BSC	France	9.213	7	0.700	14	*13*	*5*	0.285	6
Agenzia per la Promozione della Ricerca Europea	PI	Italy	6.013	9	0.824	10	13	7	*0.325*	*5*
Asociacion Madrid Plataforma Aeronautica y del Espacio	PF	Spain	0.162	65	*0.841*	*5*	11	8	0.121	19
Bwcon GmbH	BSC	Germany	2.608	25	*0.933*	*2*	13	6	0.177	13
Chambre De Commerce Et D Industriedu Luxembourg Belge Asbl	PI	Luxembourg	0.058	68	0.833	9	4	48	0.006	48
Consiglio Nazionale delle Ricerche	BSC	Italy	2.750	24	0.585	21	10	11	0.202	10
Ethniko Idryma Erevnon	PI	Greece	1.542	41	0.413	43	5	38	0.206	9
Foundation For Research And Technology Hellas	BSC	Greece	11.387	6	0.612	19	6	26	0.252	7
Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.v.	BSC	Germany	*15.759*	*4*	*0.852*	*3*	*21*	*2*	*0.762*	*2*
FundingboxAccelerator Sp. z o.o	PF	Poland	*18.096*	*2*	0.740	12	*28*	*1*	*1.000*	*1*
Institut Jozef Stefan	BSC	Poland	*13.657*	*5*	0.325	47	6	25	0.136	17
Norddanmarks Eu-Kontor	PI	Denmark	0.183	64	0.834	7	5	36	0.011	42
Norway Health Tech	PF	Norway	2.516	27	0.508	24	10	9	0.165	15
S. I. Impresa (Servizi Integrati Impresa)	PF	Italy	1.357	43	*0.848*	*4*	7	23	0.057	31
Steinbeis 2i GmbH	BSC	Germany	*22.509*	*1*	0.623	18	*19*	*3*	*0.752*	*3*
Stichting Centre Of Expertise Watertechnologie	BSC	Netherlands	7.253	8	0.476	38	9	16	0.102	27
Swietokrzyskie Centrum Innowacji Itransferu Technologii Sp (Zoo)	PI	Poland	0.547	52	0.833	8	8	20	0.014	39
Tillväxtverket	BSC	Sweden	*16.238*	*3*	0.837	6	5	37	0.189	12
United Kingdom Research and Innovation	BSC	United Kingdom	4.225	16	*0.944*	*1*	*17*	*4*	*0.336*	*4*

Table 4 (continued)

Firm	Sector[a]	Country	Betweenness centrality[b]	Betweenness rank	Closeness centrality[c]	Closeness rank	Degree centrality[b]	Degree rank	Eigenvector centrality[c]	Eigenvector rank
University of Brighton	BSC	United Kingdom	5.637	10	0.581	22	9	10	0.208	8

Italics show the top 5 values in each indicator (2014–2019)

[a]The acronyms reflected in column 2 make reference to the type of agent according to the TH model (*PF* private firms; *BSC* big science centers; *PI* public institutions)

[b]Betweenness and degree centrality ranges between 0 to infinite

[c]Closeness and eigenvector centrality ranges between 0 to 1

5 Discussion and conclusions

Knowledge generation and transfer, both between and within organizations, are fundamental processes while developing R&D activities (Cunningham and O'Reilly 2018; Easterby-Smith et al. 2008), which often derive in new products or processes through innovation. However, SMEs, due to their lack of enough tangible and intangible resources see that their efforts to individually carry out innovation are often frustrated (Brunswicker and Vanhaverbeke 2015). Consequently, they are forced to abandon these activities, or, alternatively participate in collaborative networks to develop their R&D. However, the works reviewed in the literature do not confront this issue from a sufficiently generic and holistic perspective. Within this context, the TH model, which explicitly recognizes the relevance of the interconnections between companies, public institutions, and research centers and universities, is an appropriate tool to understand the relationships between the different agents and will allow, at a later stage, the laying of foundations to spread the innovative activities among a greater number of companies.

To evaluate the success of this interaction, we use network analysis to assess the relevance of the main actors (nodes) of the process. We introduce the concept of centrality, which is borrowed from physics and computing, and we calculate the following four types of centrality to evaluate the connectivity and importance of each agent: degree centrality, betweenness centrality, eigenvector centrality, and closeness centrality. As part of our main results, we show that there is not a direct relationship between the funds obtained in the H2020 program and the economic significance of the different countries. Neither is there a clear connection between the quantity received from H2020 and the strategic positioning in terms of connectivity, or the economic relevance of the country. In this respect, Germany, Spain, and Italy represent the countries with the best power of collaboration and connectivity in the whole network. Therefore, these countries, which show higher values of centrality, can be regarded as interesting nodes to be considered for future collaborative networks.

We have also concluded that while private sector companies globally obtain the highest amount of funds to carry out innovative activities, their relative importance is lower when we refer to knowledge transfer with other agents with the aim of creating collaborations and obtaining synergies. In this sense, BSCs do not receive as much funding from H2020 but they are much better positioned in terms of centrality in the European network. Therefore, BSCs emerge as key drivers of innovation for SMEs.

This research shows that the most cohesive parts of Europe correspond to what is known as the "old continent". This means that the highest collaborative density is established between the countries in the heart of the continent and that the network between these countries will be more difficult to break. Nevertheless, there are also countries that do not belong to this group and that have achieved excellent results in these programs: examples are Spain, Armenia, Portugal, Serbia, and Croatia. It can be argued that less centralized countries, generally of smaller size, may identify large and more cohesive countries as barriers and may often find it difficult to generate potential collaborations, with the undesired consequence that potentially valuable research projects that come from these peripheral countries may be lost. The most dangerous threat that derives from these results is associated with feelings of frustration and demotivation for firms that do not belong to this collaborative network. In addition, the high competitiveness of countries with similar characteristics (high centrality and capacity for innovation) can also be understood as a threat by the other regions. Small countries have to be able to develop action policies, identify them, and try to improve their results. Therefore, countries have the potential to identify partners and join the European innovation research network for SMEs to seek the optimal balance and symmetry of the network.

An issue that is beyond the scope of this work has to do with who should be in charge of these innovative activities. In a globalized world, it can be argued that the improvement of European social welfare is even more important than the origin of the countries that contribute to it. It should also be noted that the fact that a country or an institution does not receive funding in its first collaborations in H2020 projects should not be necessarily taken as a bad thing to the extent that the establishment of relations with other countries and institutions will make these countries take a leading position in future projects and increase the funding obtained (learning effects). Within this context, we should pay special attention to the centrality and cohesiveness of the network developed because these indicators provide valuable information about expected future results. In this sense, we understand that H2020 is a powerful tool in the strengthening of the European collaborative research network.

The results that derive from the analysis have several implications for academia, management, and the public authorities. From an academic point of view, this work allows us to visualize the global European scenario of research in innovation in SMEs, advancing a step further in the subject, and filling a gap in the literature of innovation and management. As the empirical results have shown, measuring research collaborations across networks using centrality indicators may be a fruitful and complementary alternative when modelling management situations. In addition, we have introduced the TH model as an analytical tool, which gives our study a distinctive value that allows us to identify business opportunities among the different agents of the network. This type of detailed information could assist analysts in identifying where weaknesses in innovative ability occur and can support policy to encourage firms to move up the ladder of innovative capabilities. The results also clarify the role of relationships in innovation by highlighting the distinct differences between firms, institutions, and research centers. The latter increases the probability of performing R&D, possibly because the information provided by customers reduces market uncertainty. Although the details of innovation support policies are likely to differ across regions or countries to account for local conditions, the results of this study suggest there are consistent patterns between countries that occupy similar positions in the network.

From a decision-making perspective, managers should be aware of the positive spillovers that derive from collaboration. In this sense, universities and other science centers play a fundamental role in this process and should be considered as partners whose collaboration will be beneficial for both parties. Similarly, joint R&D projects with other companies may also strengthen the competitive position of SMEs. Studies such as the one developed in this research allow us to identify the entities that have a greater connectivity and are therefore more qualified to generate potential relationships. In addition, this study can be used as a tool that allows entities to visualize current relationships and predict future relationships with the aims of improving their effectiveness and sharing new joint knowledge. It can also demonstrate whether there is knowledge transfer and therefore can draw up strategies aligned with regional policies to improve territorial development.

Finally, from a policy perspective, this kind of analysis can be helpful in the process of resource allocation. The use of this type of tool will enable the identification of some of the strengths and weaknesses of the innovation system of a country. The information provided by the centrality indicators will be valuable in performing a detailed analysis that focuses on specific companies, industries, or countries with the aim of guiding policy decisions. Once we know which countries or which companies lead the R&D European scene in a given area, it would be easier to develop the appropriate actions that facilitate a firm's own competitiveness or to identify industries that can reach central positions in the networks in case of receiving initial support.

An issue that cannot be forgotten is the positive spill-overs of universities and research centers as drivers of innovation in Europe. As a consequence, it is important to provide them with the necessary resources to strengthen their interaction with SMEs to the extent that these networks will have positive effects on business (and, thus, society) performance. The knowledge that resides in universities and research centers is potentially a global asset, and policy makers should be responsible for establishing mechanisms to ensure the effectiveness of this knowledge transfer.

The secondary position of government institutions in the network leads us to think that there is not enough awareness of the specific characteristics and problems of SMEs. Public authorities should be conscious of the leverage role that they can play when adopting an active role in the R&D ecosystem. There are several dimensions that could be considered to achieve a more cohesive network: conflicts of interest between the parties undertaking the cooperation, lack of resources both in the private sphere and in that of research centers and universities, and bureaucratic obstacles related to the mechanisms needed to have access to the structural funds.

In addition, at a European level, this information can be helpful in the formulation of a roadmap for the continuation of H2020 that would favor the achievement of certain objectives. By way of example, the EU should decide whether it prefers to strengthen the position of the most important European consortia to enable them to compete with the main American and Asian leaders, at the cost of limiting the development of other companies, or if it chooses to opt for a more horizontal and less focused support that allows the development of a greater number of companies. Or perhaps it might be better to launch differentiated programs that provide different treatment for each of the two typologies mentioned.

To sum up, we believe that this research would be useful in several dimensions within the public arena, namely: (1) to enhance the government role as a provider of subsidies, (2) to assist in the process of creating new collaborations in the process of consolidating the existing ones, (3) to attract entities and strengthen linkages between them to enhance the stimulation of knowledge spillovers, (4) to contribute to the consolidation of trust among actors to create a culture of collaboration and confidence, and (5) to contribute to increased awareness of the role of innovation in SMEs and to promote the adoption of a more proactive attitude.

Beyond the progress that this research entails, the paper is not without limitations. Our analysis has been addressed by aggregating all funded research projects between 2014 and 2019. This provides us with a global picture of the whole innovation system during the period. However, we lack a dynamic vision of the process, insofar as we have not identified the possible existence of a time pattern. Therefore, we recommend that future research should increase the sample size with the aim of complementing this investigation with a year-by-year analysis that could identify this evolution over time. Future work could also explore the overview of a country or industry in an individual way. To the extent that there are specificities that characterize them, their individual analysis may provide richer and more detailed information. Similarly, it would be of interest to analyze networks between a given kind of agent, such as collaborations between BSCs. In this sense, the lack of more detailed, micro-level data constitutes a limitation insofar as it prevents the analysis of the complex relationships arising from these interactions. As a consequence, future research should try to combine network analysis and exhaustive firm level information (probably collected through surveys) in order to deepen these interactions.

Due to the holistic character of the study, it does not explore in depth the role of collaborator or coordinator adopted by each organization in the different research projects carried out by the agents of the TH model, and that may constitute an interesting further line of research. This issue could be taken into account using data that put a value on variables related to human resources. In addition, by focusing the design of the analysis on Europe, collaborations with countries outside the continent that may be of interest are left out. However, these projects represent a reduced number in H2020, and we consider that their inclusion would not affect the main results and conclusions obtained in this research. Finally, the methodology that we have employed does not allow to establish causal relationships between the resources allocated and the specific consequences that derive from the use of these resources. As a consequence, future work that tries to establish these causal relationships by using alternative methodologies would be welcome.

Acknowledgements We acknowledge financial support from the Spanish Ministry of Economy and Competitiveness and FEDER (project ECO2017-85451-R) the Regional Government of Aragón and European Social Fund (project S64_20R and projects S42_17R) and pre-doctoral grant BOAIIU/1408/2018.

References

Albors-Garrigós, J., Rincon-Diaz, C. A., & Igartua-Lopez, J. I. (2014). Research technology organisations as leaders of R&D collaboration with SMEs: Role, barriers and facilitators. *Technology Analysis & Strategic Management, 26*(1), 37–53.

Argote, L., Beckman, S. L., & Epple, D. (1990). The persistence and transfer of learning in industrial settings. *Management Science, 36*(2), 140–154.

Argote, L., & Ingram, P. (2000). Knowledge transfer: A basis for competitive advantage in firms. *Organizational Behavior Human Decision Processes, 82*(1), 150–169.

Baglieri, D., Baldi, F., & Tucci, C. L. (2018). University technology transfer office business models: One size does not fit all. *Technovation, 76–77,* 51–63.

Barge-Gil, A. (2010). Cooperation-based innovators and peripheral cooperators: An empirical analysis of their characteristics and behavior. *Technovation, 30*(3), 195–206.

Barge-Gil, A., Jesus Nieto, M., & Santamaria, L. (2011). Hidden innovators: The role of non-R&D activities. *Technology Analysis & Strategic Management, 23*(4), 415–432.

Barrie, J., Zawdie, G., & João, E. (2019). Assessing the role of triple helix system intermediaries in nurturing an industrial biotechnology innovation network. *Journal of Cleaner Production*, *214*, 209–223.

Baum, J. A., & Ingram, P. (2002). Interorganizational learning and network organization: Toward a behavioral theory of the interfirm. *The economics of choice, change, and organization: Essays in memory of Richard M. Cyert*, 191–218.

Beauchamp, M. A. (1965). An improved index of centrality. *Behavioral Science, 10*(2), 161–163.

Bogers, M., Zobel, A. K., Afuah, A., Almirall, E., Brunswicker, S., Dahlander, L., & Hagedoorn, J. (2017). The open innovation research landscape: Established perspectives and emerging themes across different levels of analysis. *Industry and Innovation*, *24*(1), 8–40.

Bonacich, P. (1987). Power and centrality: A family of measures. *American Journal of Sociology, 92*(5), 1170–1182.

Brunswicker, S., & Vanhaverbeke, W. (2015). Open innovation in small and medium-sized enterprises (SMEs): External knowledge sourcing strategies and internal organizational facilitators. *Journal of Small Business Management, 53*(4), 1241–1263.

Cano-Kollmann, M., Cantwell, J., Hannigan, T. J., Mudambi, R., & Song, J. (2016). Knowledge connectivity: An agenda for innovation research in international business. *Journal of International Business Studies, 47*(3), 255–262.

Coccia, M. (2019). Why do nations produce science advances and new technology? *Technology in Society, 59,* 101124.

Coccia, M., & Wang, L. (2016). Evolution and convergence of the patterns of international scientific collaboration. *Proceedings of the National Academy of Sciences, 113*(8), 2057–2061.

Crick, D., & Spence, M. (2005). The internationalisation of 'high performing' UK high-tech SMEs: a study of planned and unplanned strategies. *International Business Review, 14*(2), 167–185.

Cunningham, J. A., & O'Reilly, P. (2018). Macro, meso and micro perspectives of technology transfer. *The Journal of Technology Transfer, 43*(3), 545–557.
Darroch, J. (2005). Knowledge management, innovation and firm performance. *Journal of Knowledge Management, 9*(3), 101–115.
de Jong, J. P. J., & Vermeulen, P. A. M. (2006). Determinants of product innovation in small firms: A comparison across industries. *International Small Business Journal: Researching Entrepreneurship, 24*(6), 587–609.
Dhanaraj, C., & Parkhe, A. (2006). Orchestrating innovation networks. *Academy Management Review, 31*(3), 659–669.
Easterby-Smith, M., Lyles, M. A., & Tsang, E. W. K. (2008). Inter-organizational knowledge transfer: Current themes and future prospects. *Journal of Management Studies, 45*(4), 677–690.
Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix—University-industry-government relations: A laboratory for knowledge based economic development. *EASST Review, 14*(1), 14–19.
Farinha, L., Ferreira, J., & Gouveia, B. (2016). Networks of innovation and competitiveness: A Triple Helix case study. *Journal of Knowledge Economy, 7*(1), 259–275.
Fernández-Sastre, J., & Montalvo-Quizhpi, F. (2019). The effect of developing countries' innovation policies on firms' decisions to invest in R&D. *Technological Forecasting and Social Change, 143,* 214–223.
Freeman, L. C. (1977). A set of measures of centrality based on betweenness. *Sociometry, 40*(1), 35–41.
Guerrero, M., Urbano, D., Fayolle, A., Klofsten, M., & Mian, S. (2016). Entrepreneurial universities: emerging models in the new social and economic landscape. *Small Business Economics, 47*(3), 551–563.
Gunasekara, C. (2006). Reframing the role of universities in the development of regional innovation systems. *The Journal of Technology Transfer, 31*(1), 101–113.
Gupta, A. K., & Govindarajan, V. (2000). Knowledge flows within multinational corporations. *Strategic Management Journal, 21*(4), 473–496.
Hervas-Oliver, J. L., Garrigos, J. A., & Gil-Pechuan, I. (2011). Making sense of innovation by R&D and non-R&D innovators in low technology contexts: A forgotten lesson for policymakers. *Technovation, 31*(9), 427–446.
Huang, C., Arundel, A. V., & Hollanders, H. J. G. M. (2010). *How firms innovate: R&D, non-R&D, and technology adoption*. Working Papers 027, United Nations University—Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT).
Huenteler, J., Schmidt, T. S., Ossenbrink, J., & Hoffmann, V. H. (2016). Technology life-cycles in the energy sector—Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change, 104,* 102–121.
Huggins, R., Johnston, A., & Stride, C. (2012). Knowledge networks and universities: Locational and organisational aspects of knowledge transfer interactions. *Entrepreneurship & Regional Development. An International Journal, 24,* 475–502.
Huggins, R., Prokop, D., & Thompson, P. (2019). Universities and open innovation: The determinants of network centrality. *The Journal of Technology Transfer*. https://doi.org/10.1007/s10961-019-09720-5.
Inkpen, A. C., & Tsang, E. W. K. (2005). Social capital, networks, and knowledge transfer. *Academy Management Review, 30*(1), 146–165.
Kotabe, M., Martin, X., & Domoto, H. (2003). Gaining from vertical partnerships: knowledge transfer, relationship duration, and supplier performance improvement in the U.S. and Japanese automotive industries. *Strategic Management Journal, 24*(4), 293–316.
Lamine, W., Mian, S., Fayolle, A., Wright, M., Klofsten, M., & Etzkowitz, H. (2018). Technology business incubation mechanisms and sustainable regional development. *The Journal of Technology Transfer, 43*(5), 1121–1141.
Latorre, M. P., Hermoso, R., & Rubio, M. A. (2017). A novel network-based analysis to measure efficiency in science and technology parks: The ISA framework approach. *The Journal of Technology Transfer, 42*(6), 1255–1275.
Li, Y., Arora, S., Youtie, J., & Shapira, P. (2018). Using web mining to explore Triple Helix influences on growth in small and mid-size firms. *Technovation, 76–77,* 3–14.
Link, A. N., & Sarala, R. M. (2019). Advancing conceptualisation of university entrepreneurial ecosystems: The role of knowledge-intensive entrepreneurial firms. *International Small Business Journal, 37*(3), 1–22.
Nepelski, D., & Piroli, G. (2018). Organizational diversity and innovation potential of EU-funded research projects. *The Journal of Technology Transfer, 43*(3), 615–639.
Nordman, E. R., & Melén, S. (2008). The impact of different kinds of knowledge for the internationalization process of Born Globals in the biotech business. *Journal of World Business, 43*(2), 171–185.

Nordman, E. R., & Tolstoy, D. (2016). The impact of opportunity connectedness on innovation in SMEs' foreign-market relationships. *Technovation, 57–58,* 47–57.

Pérez-Nordtvedt, L., Kedia, B. L., Datta, D. K., & Rasheed, A. A. (2008). Effectiveness and efficiency of cross-border knowledge transfer: An empirical examination. *Journal of Management Studies, 45*(4), 714–744.

Rammer, C., Czarnitzki, D., & Spielkamp, A. (2009). Innovation success of non-R&D-performers: Substituting technology by management in SMEs. *Small Business Economics, 33*(1), 35–58.

Rammer, C., Kinne, J., & Blind, K. (2020). Knowledge proximity and firm innovation: A microgeographic analysis for Berlin. *Urban Studies, forthcoming.*. https://doi.org/10.1177/0042098018820241.

Ranga, L. M., Debackere, K., & Von Tunzelmann, N. (2003). Entrepreneurial universities and the dynamics of academic knowledge production: A case study of basic vs applied research in Belgium. *Scientometrics, 58*(2), 301–320.

Ranga, L. M., Miedema, J., & Jorna, R. (2008). Enhancing the innovative capacity of small firms through triple helix interactions: challenges and opportunities. *Technology Analysis & Strategic Management, 20*(6), 697–716.

Simonin, B. L. (1999). Ambiguity and the process of knowledge transfer in strategic alliances. *Strategic Management Journal, 20*(7), 595–623.

Swan, J., Newell, S., Scarbrough, H., & Hislop, D. (1999). Knowledge management and innovation: Networks and networking. *Journal of Knowledge Management, 3*(4), 262–275.

Szulanski, G. (1996). Exploring internal stickiness: Impediments to the transfer of best practice within the firm. *Strategic Management Journal, 17,* 27–43.

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning, 43*(2–3), 172–194.

Tether, B. S., & Tajar, A. (2008). Beyond industry–university links: Sourcing knowledge for innovation from consultants, private research organisations and the public science-base. *Research Policy, 37*(6–7), 1079–1095.

Tsai, W. (2001). Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. *The Academy of Management Journal, 44*(5), 996–1004.

Xu, L., Li, J., & Zhou, X. (2019). Exploring new knowledge through research collaboration: The moderation of the global and local cohesion of knowledge networks. *The Journal of Technology Transfer, 44*(3), 1–28.

Zeng, S. X., Xie, X. M., & Tam, C. M. (2010). Relationship between cooperation networks and innovation performance of SMEs. *Technovation, 30*(3), 181–194.