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ICT research networks and regional competitiveness:

An analysis of the 7th Framework Program

Authors

Ana Salomé García-Muñiz

REGIOlab, Department of Applied Economics

University of Oviedo

San Francisco, 3 33003 Oviedo Spain

Email: asgarcia@uniovi.es

ORCID iD: <https://orcid.org/0000-0003-2783-8041>

María Rosalía Vicente

Department of Applied Economics

University of Oviedo

San Francisco, 3 33003 Oviedo Spain

Email: mrosalia@uniovi.es

ORCID iD: <https://orcid.org/0000-0001-7826-8494>

Margarita Billon¹

Department of Economic Structure and Development Economics

Universidad Autónoma de Madrid

Ciudad universitaria de Cantoblanco, 28049 Madrid Spain

Email: margarita.billon@uam.es

ORCID iD: <https://orcid.org/0000-0003-4860-9133>

¹ Corresponding author

Abstract

Using Social Network Analysis and the novel concept of bridging centrality this paper investigates the links generated by the research networks created by two of the European Union-funded Programs, the 7th Framework Program (FP7) and the ICT action of the Competitiveness and Innovation Framework Program (CIP) and their impacts on regional competitiveness. Our findings show a positive impact on the competitiveness of both networks. Those regions with higher capacities to establish bridging paths tend to show higher levels of competitiveness. Moreover, our results indicate that these effects differ between research and diffusion networks. Whereas the FP7-related network impacts all the dimensions of competitiveness, the CIP influences competitiveness only through the innovative channel. Our results highlight the importance of facilitating intra- and inter-regional collaboration networks between core and peripheral regions in Europe.

Keywords: EU Framework Program; R&D networks; regional competitiveness; Information and Communication and Technologies (ICT), Social Network Analysis

1. Introduction

Enhancing competitiveness has been a critical goal of the European research and development (R&D) policy since its origin (Laredo 1998, Reillon 2017). In the Lisbon Agenda, the European Union (EU) aspired to “*become the most competitive and dynamic knowledge-based economy in the world*” (European Parliament, 2000). To that end, the EU policy has devoted considerable efforts to foster research and innovation activities. In this vein, the creation and extension of collaborative research networks have been revealed as a key driver for knowledge creation and knowledge spillovers that are considered sources of national and regional competitiveness in Europe (Tödtling, Lehner and Trippl 2006; Capello and Cerisola 2019). Research and innovation are instruments to increase productivity, enlighten competitiveness, enhance smart and sustainable economic growth, and generate knowledge-based jobs. The Framework Programs (FPs) for Research and Technological Development is the main instrument of the European R&D policy and the pillar of the European Research Area (Cassi et al. 2008; Heller-Schuh 2011). Their relevance is explained by their positive effects on technological innovation and the economic and social development of the EU (García-Muñiz and Vicente 2018).

Previous studies focused on analyzing the general features of the participation in FPs (European Commission 2015a, 2016a, 2016b, 2016c), identifying the relevant transnational networks of collaborative research and the role played by the most central organizations within the FPs (Heller-Schuh et al. 2011). Other researchers have explored the results and impacts of FPs participation (Arnold 2012; Muscio, Reid and Rivera-León 2015; Nepelski and Piroli 2018), the formation of knowledge spillovers and their influence on innovation (Di Cagno et al. 2016), or the positioning of actors in the network and the effects of knowledge transfer between Programs (European Commission 2015a). The academic literature has also shown a growing interest in the characteristics of regional R&D networks and the information and knowledge flows created across them (Wen, Qualls and Zeng 2021; Chen et al., 2020; Breschi et al. 2009; Pandza, Wilkins and Alfoldi 2011) as well as on the effects of the FP regional knowledge networks on technological specialization (Ciffolilli and Muscio 2018; Muscio and Ciffolilli 2018). However, although the available studies have shown positive impacts of FPs on the creation of R&D networks, the academic literature that investigates the effects of these networks on regional economic performance is still scarce (Arnold 2012;

Cassi et al. 2008; Muscio, Reid and Rivera-León 2015; Piirainen 2018) and particularly those studies exploring the outcomes in terms of competitiveness across the EU (Muscio and Ciffolilli 2018). In addition to that, most of them have considered the amount of funding or the number of projects to assess the participation in FPs whereas the analysis of the research links has been mainly employed to evaluate knowledge outputs (i.e., patents, scientific papers).

Within this context, the present study aims to investigate the research networks created by two of the EU-funded programs and their impacts on regional competitiveness focusing especially on the ICT priority in these programs. Over the last three decades Information and Communication Technologies (ICTs) have substantially changed the socio-economic landscape, facilitating not only new ways of communication and doing business but also faster access and diffusion of information and knowledge. In the EU, the Digital Agenda, included in the Europe 2020 strategy, recommends fostering the potential of ICTs to promote growth, competitiveness, and innovation. One of the keys of the Digital Agenda is encouraging research and innovation activities to “maintain Europe's competitive edge through increased coordination and elimination of Europe's fragmented efforts”². The creation of the Digital Single Market aims to achieve smart, sustainable, and inclusive economic growth. Business model transformation allows companies to take advantage of the opportunities associated with big data, fast and ultra-fast internet and digitized processes as interoperable services and applications. Thus, OECD (2015) highlights data-driven innovation as a key in the generation and/or improvement of new products, processes, and organizational tools associated with ICT. Innovation and ICT diffusion are heavily influenced by investments in R&D and the connections and knowledge exchanged between scientific, Higher education institutions, and businesses.

Our analysis relies on Social Network Analysis and the concept of bridging centrality (Bergé et al. 2017) to explore the links created due to the 7th Framework Program (FP7) in the field of Information and Communication Technologies (ICT) - that run from 2007 to 2013- and a contemporaneous program of FP7, the ICT action of the Competitiveness and Innovation Framework Program (CIP). While the FP was mainly focused on technological

² <https://ec.europa.eu/digital-single-market/>

research (European Commission, 2015b), the CIP aimed at encouraging technological diffusion targeting small-and-medium-sized enterprises (SMEs). In contrast to previous studies that analyzed FP-based networks (FP6) along with other complementary diffusion networks (Cassi et al. 2008), we examine FP7 and CIP networks separately to identify possible common patterns in the collaborative created links and to evaluate their potential effects on competitiveness. The analysis is overtaken to a regional level. The regional dimension nowadays is increasingly important. The literature has shown that cross-regional differences in economic growth are correlated with asymmetries in the conditions for creating, accumulating, and transmitting knowledge and innovation (Clarysse and Muldur, 2001).

We contribute to the academic literature by providing new evidence about the economic effects of participation in the European Framework Programs. By focusing on regional competitiveness our results ultimately may expand our knowledge on the absorption capacity associated with FPs funding at the regional level. In a period of increasing debate on the most suitable strategies for technological development and specialization paths for the European regions (De Noni, Ganzaroli and Pilotti 2021), the present research becomes relevant considering that the new elements of Horizon Europe emphasize once again the significance of fostering the EU's industrial competitiveness and its innovation performance through market-creating innovations (European Commission, 2021).

Competitiveness is a complex issue that has multiple facets and diverse definitions (Henderson, 2008; Delgado et al., 2012; World Economic Forum, 2015). Januškaitė and Užienė (2018) review the basic factors influencing regional competitiveness. Many researchers agree that knowledge spillovers, innovative and competitive industries are key to regional competitiveness (Porter, 1990; OECD, 2016, among others). In this work, competitiveness is measured by the multidimensional index developed by European Commission (Dijkstra, Annoni and Kozovska 2011), the European Regional Competitiveness Index (RCI). Regional competitiveness is defined in the RCI as “the ability of a region to offer an attractive and sustainable environment for firms and residents to live and work” (Annoni, Dijkstra, Gargano, 2017:2). This definition supports more than a purely economic emphasis on competitiveness and extends the scope by incorporating social factors.

Moreover, it allows the incorporation of the concept of sustainable development as suggested by the Sustainable Development Goals of the United Nations.

The remainder of the paper is structured as follows. Section 2 reviews the literature on Framework Programs in the context of knowledge networks and their impacts on competitiveness. Section 3 presents the methodological approach and data sources. Section 4 shows the results. Finally, the conclusions and discussion of the results are presented in Section 5.

2. Knowledge networks, Framework Programs and competitiveness

In a context where the content of knowledge is characterized for being more and more complex, tacit, and specific, R&D collaboration networks have demonstrated to be a strategic tool that facilitates the exchange, access, and production of new knowledge and the development of innovations (Sherngell 2019). The intra- and inter- EU regional collaborations and knowledge interactions among the several regional actors may facilitate the development of complementary activities and knowledge spillovers at the regional level (Capello and Cerisola, 2019; Sherngell, 2019) favoring a more efficient and strategic access to new knowledge that ultimately may lead to innovation competitive advantages (Tödtling Lehner and Trippl 2006; Arnold, 2012). By promoting the exchange and transfer of knowledge and innovation activities, R&D collaboration networks become a critical factor to boost regional competitiveness (Piazza et al. 2019; Tóth et al. 2021) although the effects may depend on the regional economic development model and regions' network characteristics (De Noni Orsi and Belussi 2018; Capello and Cerisola, 2019), among other factors.

Over the past decades, studies on collaboration networks have increased considerably due to the growing interest in the role played by regional innovation as an instrument for fostering regional competitiveness (Piazza et al. 2019). A variety of studies have investigated the outcomes of the FP framework in the creation of knowledge through collaboration networks (Arnold 2012; Fabrizi, Guarini and Meliciani 2018; Muscio, Rivera Leon and Reid 2015; Piirainen 2018; Wanzenböck, Scherngell and Lata 2014). Specific attention has been

devoted to exploring the characteristics of regional networks and in particular their structural properties and the regional factors that explain the position of actors in the network (Amoroso, Coad and Grassano 2018; Graf and Kalthaus 2018; Piazza et al. 2019; Wanzenböck, Scherngell and Lata 2015). The academic evidence shows that the strategic position in R&D collaboration networks favors knowledge access through both direct and indirect links in the network (Wanzenböck et al. 2015). In this vein, the type of links created and the network features become critical factors when the local pool of knowledge assets is limited. The more varied the links, the more diverse the access to knowledge. However, although some studies are exploring the impacts of innovation networks on economic performance, the empirical research investigating the impacts of FPs R&D networks on the regional economic performance, and in particular on the effects on competitiveness, are still scarce (Arnold 2012; Muscio, Reid and Rivera-León 2015; Muscio and Cifforilli 2018).

To achieve this competitiveness goal, special attention has been paid to ICT given its pervasive nature and its potential to boost innovation and competitiveness throughout the economy (Falk and Biagi 2015; Nepelski et al. 2017). In this sense, ICT has always been a priority for the EU's research policy (Alabau 2001). These technologies have been generally considered "*as the main infrastructure of the knowledge (R&D-based) economy*" (Pieri, Vecchi and Venturini 2018:1) and constitute an essential component of the EU's strategy for growth and development. The EU highlights the need to strengthen the intensity of R&D efforts in this field to reach American levels and safeguard long-term competitiveness (European Commission 2009).

In this context, the FP7 focused on the support of R&D in the European ICT industry to implement ICT solutions and services for sustainable development and well-being. Meanwhile, the key feature of the CIP -which was to be complementary to the FP7- was deployment, stimulating technological and organizational innovations and, particularly, a wider uptake of new ICT among SMEs (Vickery et al 2011). The objectives of both Programs were aligned with those of the i2010 and the subsequent Digital Agenda and aim to: (i) strengthen the single European information space; (ii) promote innovation through boosting ICT investment and diffusion; (iii) and contribute to the development of efficient and effective public services to achieve an information society "for all", improving citizens' quality of life.

Several papers have previously studied the development of ICT R&D networks in the context of FPs. Special attention has been paid to their characteristics and dynamics of evolution (Protegeru, Caloghirou and Siokas 2010), the complementarities between research and diffusion networks and their links with regional innovation systems (Cassi et al. 2008), the connections with global ICT networks (Breschi et al. 2009), the determinants of the intensity of regional cooperation (Cecere and Corrocher 2015), the impact of FP funding on ICT-related knowledge outputs (i.e., ICT patents, Varga and Sebestyén 2017), the societal impact (De Jong et al. 2014 based on case studies), and the effects of projects' organizational diversity on innovation potential (Nepelski and Piroli 2018), among others. Nonetheless, little has been done on their potential effects on competitiveness (Muscio, Reid and Rivera-León 2015).

3. Methodology and data

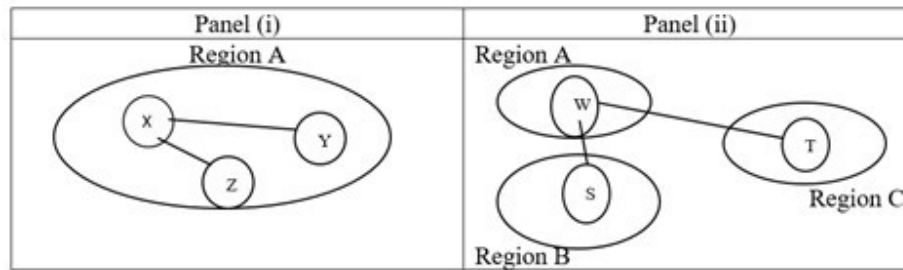
The position of regions and their role in the network is identified employing Social Network Analysis (SNA). This is an accepted methodology by the European Commission to evaluate the qualitative and quantitative results of research programs (European Commission 2015a, 2015b, 2016d). Moreover, the SNA framework is widely used to study partnerships in FP projects (Barber, Fischer and Scherngell 2011; Breschi et al 2009; Cassi et al 2008; Cecere and Corrocher 2015; Crespo, Suire and Vicente 2015; Di Cagno et al. 2016; Maggioni and Uberti 2009; Must 2010; Scherngell and Lata 2013; Wanzenböck, Scherngell and Lata 2015).

3.1. Network analysis: Bridging centrality

A set of nodes (either individual, firms, regions, or countries) connected by some relational tie is defined as a network. Following Breschi et al. (2009), regions i and j are linked by an edge if they have organizations that have been partners in at least one project. As a result, a weighted network $G = \{g_{ij}\}$ is created in which the nodes are the regions, and the edges are the research relationships established between them in the context of FP7/CIP projects. Within these networks, both codified and tacit knowledge are gathered, transmitted, and shared, which generates organizational, transnational, and disciplinary abilities. Network analysis allows us to discover the pattern of relationships and the flows of knowledge

between the members of the network. Such flows depend not only on the direct relationship with each other but also on their relationships with everyone else. In this sense, Wazenböck, Scherngell and Brenner (2014) indicate that sustained and successful knowledge creation not only depends on regions' internal conditions but also requires them the ability to quickly access external knowledge sources; hence, the importance of their position in inter-regional knowledge networks. Traditional social network measures fail to detail the microstructure of regional R&D networks. Specifically, these measures do not allow to fully assess the two dimensions of regional research links, i.e., internal links and interregional links. Figure 1 shows two situations of a region A having a degree value of 2, that is, it has two direct links. However, the situations are completely different: on the left panel, the two direct links correspond to internal (within a region) links; while, on the right panel, the two direct links of A are interregional (between regions) links.

Figure 1. Internal versus inter-regional links

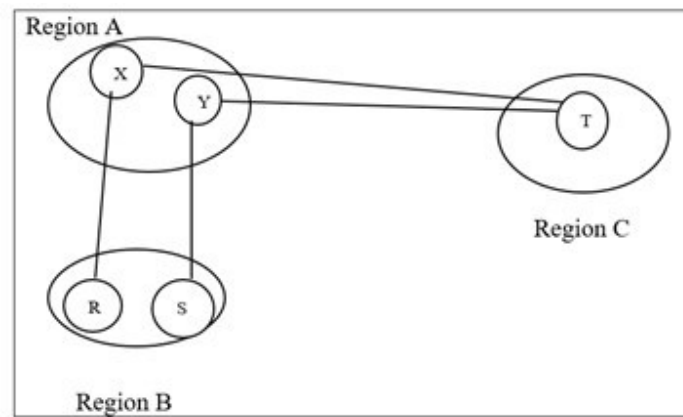


The bridging centrality proposed by Bergé, Wanzenböck and Scherngell (2017), addresses the global study within and between region's links in R&D networks by taking into account the micro-level actors. The notion of bridging agent represents an intermediate node acting between regions indirectly connected. A node with a bridge role has an advantaged structural position not only for accessing diverse knowledge but also for its diffusion.

Figure 2 shows the concept of bridges in a network. Region A has two organizations X and Y, which have direct links with organizations in other regions: X with R and T in regions B and C; and Y with S and T in regions B and C, respectively. X and Y play a central role in the network since they have access to the knowledge pools of both regions, B and C, and facilitate the flows of knowledge between these two regions, which are not directly connected. In this sense, organizations X and Y can be said to be bridging agents. Accordingly, region A has a bridging position within the network: it builds a bridge between

regions B and C, which are not directly connected. This bridging role can be also associated with the concept of knowledge broker in terms that it controls the access to knowledge spillovers due to an advantageous position in the network: Region A controls the knowledge flows between regions B and C since they all go through A.³

Figure 2. Bridges in a network



Analytically, the centrality of region i ($i=1, \dots, n$), based on the number of bridging actors (BC_i), is calculated as follows (Bergé, Wanzenböck and Scherngell 2017):

$$BC_i = q_i s_i (1 - h_i) \quad (1)$$

The number of bridges depends on the following three elements: (i) the participation intensity (q_i) in R&D projects; (ii) the relative outward orientation (s_i); and (iii) the diversification of network linkages ($1-h_i$).

The first element, the participation intensity (q_i) of region i , is defined as its number of outer links, that is, the total number of links of i (g_i) excluding region-internal (g_{ii}):

³ A vast literature collects the relevance of brokerage role in the generation and diffusion of innovation (Rodan and Galunic 2004; Burt 2009, among others).

$$q_i = g_i - g_{ii} \quad (2)$$

Hence, it reflects the region's links with other regions. The size of the region may influence its participation intensity since a bigger size implies a higher possibility of having more agents connected to other regions that might establish bridges with third regions.

The second element, the relative outward orientation (s_i) of region i , is calculated as the ratio between the number of region's outer (interregional) links (q_i) and its total number of links (g_i):

$$s_i = \frac{q_i}{g_i} \quad (3)$$

The higher number of region-internal links would have some lesser influence as the possibility of connection with other regions is reduced.

Finally, the third element, the diversification of links of region i can be measured as $(1-h_i)$ where h_i is the Herfindahl-Hirschman (HH) index, defined as:

$$h_i = \sum_{i \neq j} \left(\frac{g_{ij}}{q_i} \right)^2 \quad (4)$$

which ranges from 0 to 1. The closer the value of the index to 1, the higher concentration in the links and the lower the probability of building bridges among other regions.

This measure of bridging centrality (BC_i) takes positive values with no upper bound. To make easier its interpretation, Bergé, Wanzenböck and Scherngell (2017) normalize it between 0 and 1⁴.

⁴ Formally, the measure is normalized as follows: $\frac{(BC_i - BC_{\min})}{(BC_{\max} - BC_{\min})}$

3.2. Data

Our analysis uses three types of data sources. In the first place, data are sourced from European Union (2015c) databases on the FP7 and the CIP, with a focus on projects in the ICT field. We collect data on ICT projects, the organizations, and the regions where there are located.

In the second place, data are collected from the European Regional Competitiveness Index (RCI) developed by the European Commission (Dijkstra, Annoni and Kozovska 2011). Competitiveness is generally defined as the “*set of institutions, policies and factors that determine the level of productivity of a country*” (Schwab and Porter 2007: 13). While there is wide consensus about the use of productivity as a measure of national competitiveness, its application to regions or cities has been subjected to much debate (Kitson, Martin and Tyler 2004). Nonetheless, the lack of alternative measures has led to its use when evaluating the impact of FPs (Muscio, Reid and Rivera-León 2015). Not until recently, alternative indicators of regional competitiveness have been designed. The European Commission launched the European Regional Competitiveness Index for the first time in 2010. According to the RCI, “*regional competitiveness can be defined as the ability to offer an attractive and sustainable environment for firms and residents to live and work*” (Dijkstra, Annoni and Kozovska 2011:4). Within this definition, both economic and social elements are considered.

The RCI methodology is based on the Global Competitiveness Index by the World Economic Forum (Schwab and Porter 2007). The RCI is built as a composite index which consists of three sub-indices (basic, efficiency, and innovation) and 11 pillars. The basic sub-index includes five pillars: institutions, macroeconomic stability infrastructure health, and basic education. These elements represent the key basic drivers of all types of economies. The efficiency sub-index considers factors related to the availability of skilled labor force and efficient labor markets including three pillars: higher education, training and lifelong learning, labor market efficiency and market size. Finally, the innovation sub-index entails three pillars: technological readiness, business sophistication and innovation (Annoni, Dijkstra and Gargano 2017). The RCI presents similar limitations to other composite indices: variable selection might imply a certain degree of subjectivity and biases; the trade-off between the number of indicators to include and regions to cover; and complexity reduction

to a single figure from which simplistic conclusions might be drawn. Additionally, the current RCI does not take into account the increasing importance of the dimension of environmental sustainability.

For the present analysis, RCI data for the year 2016 is used. While the FP7 and the CIP finished in 2013, it is reasonable to think that their impacts on the economy may be delayed as the research process is time-consuming process (Griliches 1979, among others). R&D activities imply the coordination of different agents and institutions and complex processes so that they might not have an economic effect until several years have elapsed.

Finally, some socioeconomic data are collected from Eurostat. To properly assess the effects of EU's supported knowledge networks over regional competitiveness, the following set of controls is considered: Gross Domestic Product per capita, R&D expenditure, and Human Resources in High Technology. For each of these indicators, we calculate the average value over the period 2007-2013.

3.3 Variables

Based on the sources previously mentioned, we have considered several variables to explore the potential links between regional competitiveness and ICT knowledge networks (Table 1). Specifically, several linear regressions are tested with the RCI and its sub-indices (BASIC, EFFICIENCY and INNOVATION) as dependent variables; and the BC score and its components -participation intensity (PARTICIPATION), relative outward orientation (OUTWARD), and linkages diversification (DIVERSIFICATION)- as independent variables. The analysis over the sub-indices will allow us to identify potentially different effects of regional knowledge links over the pillars that define competitiveness.

Other factors that may influence regional competitiveness have been controlled for. In the first place, regional Gross Domestic Product (GDP) per capita. While GDP is a traditional measure of outcome competitiveness (Aiginger 2006), it can also be a proxy for the economic resources and structure that determine a territory's level of competitiveness. By including it on the right-hand side of the competitiveness equation, we are able to control for the influence of these economic resources and identify any link that ICT collaborative relationships may have over "beyond-the-GDP" competitiveness (Aiginger, Bärenthaler-Sieber and Vogel 2013). Defining competitiveness requires other indicators beyond the GDP

goal. Human capital and innovation capabilities are two of the main drivers of competitiveness in the knowledge economy (Acemoglu 2003). Accordingly, we include R&D expenditure as a percentage of GDP (R&D) and the percentage of the population with tertiary education (HKAPITAL).⁵ Finally, country dummies are included in the estimations to control for any unobserved country-specific effects.

Table 1. Variable description

Variable	Description
<i>Dependent variables</i>	
RCI	EU Regional Competitiveness Index score
BASIC	RCI Basic sub-index
EFFICIENCY	RCI Efficiency sub-index
INNOVATION	RCI Innovation sub-index
<i>Independent variables</i>	
BC_SCORE _{FP7}	Bridging centrality (FP7)
PARTICIPATION _{FP7}	Participation intensity (FP7)
OUTWARD _{FP7}	Relative outward orientation (FP7)
DIVERSIFICATION _{FP7}	Diversification index (FP7)
BC_SCORE _{CIP}	Bridging centrality (CIP)
PARTICIPATION _{CIP}	Participation intensity (CIP)
OUTWARD _{CIP}	Relative outward orientation (CIP)
DIVERSIFICATION _{CIP}	Diversification index (CIP)
<i>Control variables</i>	
GDP	Gross Domestic Product/capita
R&D	R&D expenditure as percentage of GDP
HKAPITAL	Percentage of population with tertiary education
COUNTRY	Country dummies

4. Results

4.1. Regional ICT research and diffusion networks

A summary of the participation in ICT projects financed by the FP7 and the CIP (hereinafter referred to as FP7-ICT and CIP-ICT, respectively) is presented. These networks have been built by considering that two regions *i* and *j* are linked if organizations located in

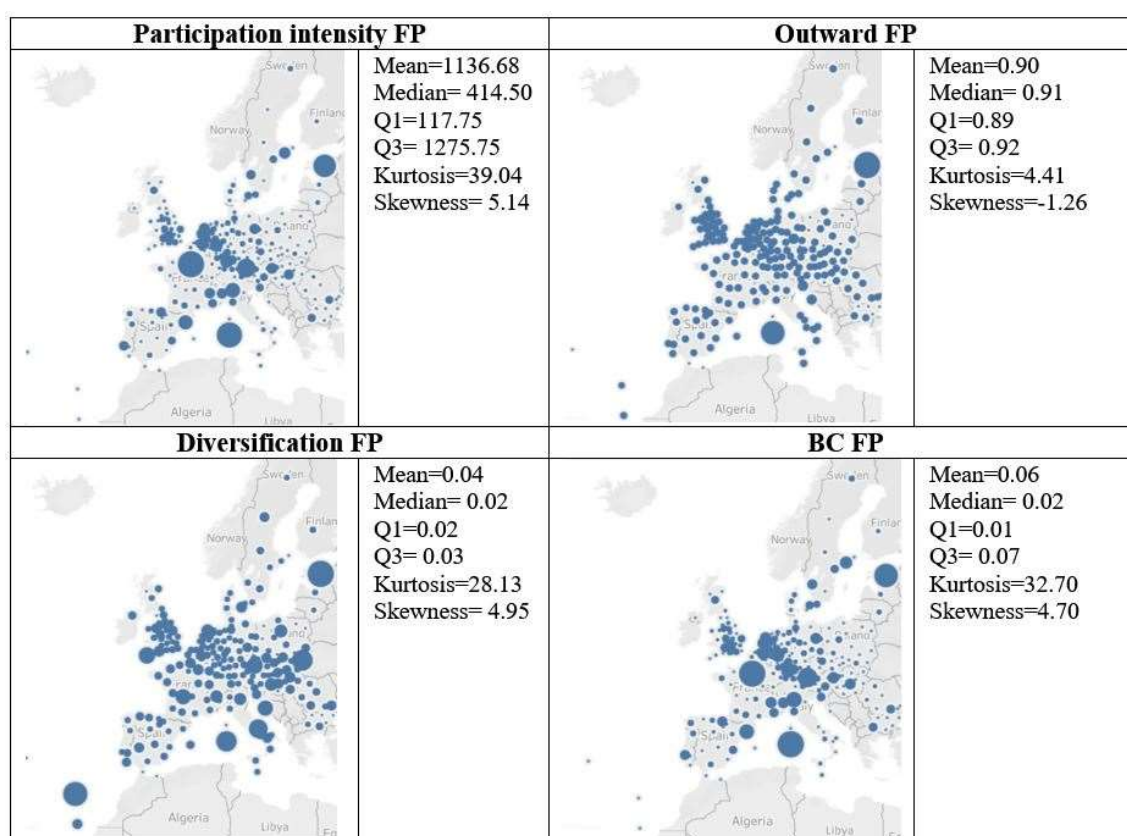
⁵ Several alternative measures of innovation and human capital have been checked. The two variables finally considered show low correlations between them and hence, limit potential problems of multicollinearity.

them have been partners in at least one project. Similarly to Cassi et al. (2008), these links represent channels of collaboration, knowledge, and information transfer.

FP7-ICT network contains collaboration flows between 245 NUTS2 regions. This network is based on a total of 2,393 projects and 13,873 organizations producing a ratio between the number of collaboration links and the number of potential links (i.e. density) of 0.403. These figures are lower in the CIP program: the total numbers of projects and organizations are 233 and 2,720, respectively and the density is 0.291. Thus, inter-regional collaborations in the CIP program are lower.

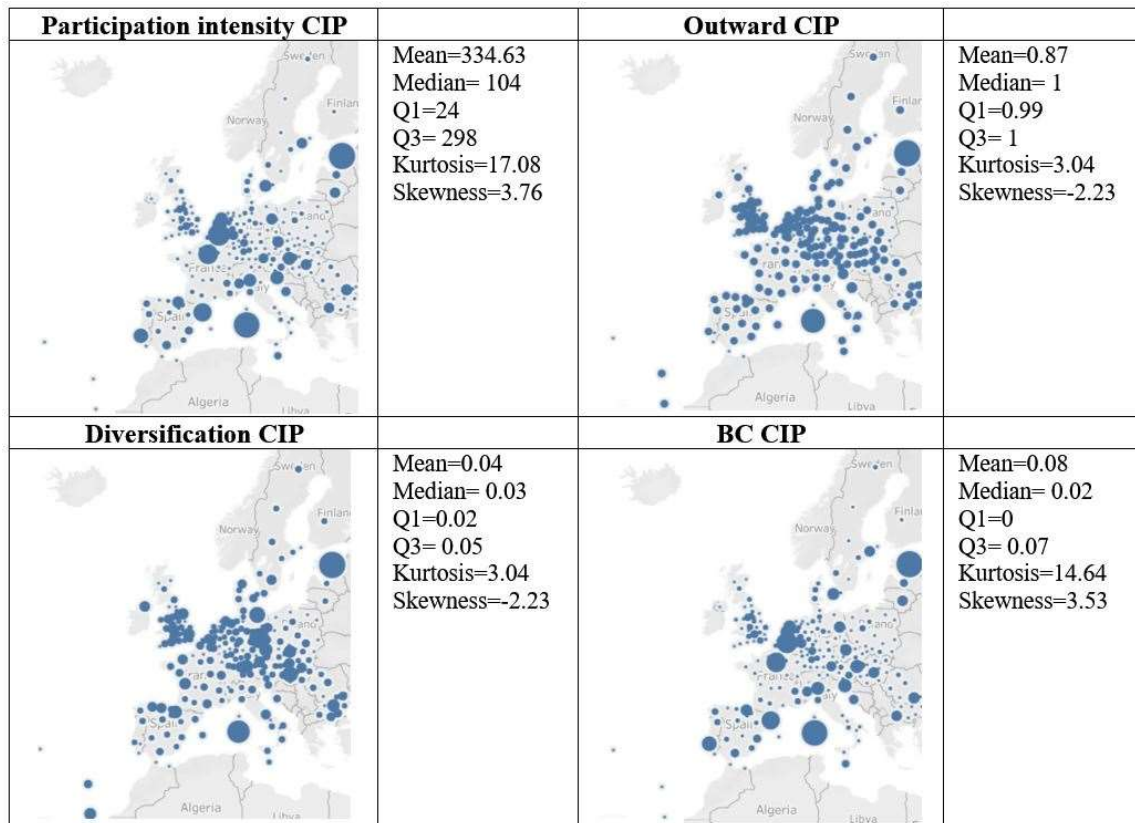
The three components of the BC and the BC are described in Figure 3 and Figure 4, for the FP7-ICT and CIP-ICT, respectively,

Figure 3. Results BC Components. FP7-ICT



Source: Own elaboration.

Figure 4. Results BC Components. CIP-ICT



Source: Own elaboration.

The participation intensity in FP7-ICT is on average 1136.68, which means that regions display on average 1136.68 collaboration-research links with other regions. This value is much higher than the median of 414.50, endorsing the right-skewed distribution of the research links with other regions. Thus, many regions present a lower relational capacity to establish bridges between other regions. This feature is also present in the CIP-ICT network, although in a minor degree. The mean participation intensity in CIP is 334.64 and the median is 104.

Appealing the relative outward orientation, the median is 91% and 100% in FP7-ICT and CIP-ICT, respectively. In the FP7-ICT for half of the regions, more than 91% of their research collaborations are established with at least one institution outside the region. In the

case of the CIP-ICT, it is remarkable that for half of the regions 100% of their links are inter-regional. The openness of a region in concerning knowledge strategies is high in both programs. However, the diversification is very low with a 0.04 mean in both programs. This implies that collaboration research linkages are concentrated in some regions. Although the regions are opened to research collaboration with others, they have failed to implement a diversified inter-regional research structure. The diversification structure is slightly left-skewed. Few regions present a high diversification and therefore can inhibit lock-in frameworks and renovate their regional knowledge assets.

As a result, the average normalized bridging centrality values (BC) are very low: 0.06 and 0.08 for FP7-ICT and CIP-ICT networks, respectively. Hence, in both ICT research and deployment networks, many regions gather a limited ability to benefit from access to diversified knowledge or exploit external knowledge, although the dispersion around the mean BC is higher given the kurtosis of the distributions. The distribution of bridging centrality is extremely right-skewed, especially in the FP7-ICT network. Few regions present a high number of bridging actors with access to varied pools of ICT knowledge. They represent the base to foster innovation between agents in the network. The bigger circle marks in the figure of BC point out the outstanding regions in terms of BC. The Top-20 regions in terms of their capacity to bridge paths are well known European ICT clusters (see Hansen and Serin 2010, for an overview of ICT clusters) and are the same in both networks, with slight differences in the positions in the rankings (Vicente, García-Muñiz and Billon 2020 for detail about the top and bottom regions in bridging centrality). A high correlation between the BC results is presented (the value of Pearson's correlation coefficient is 0.78, being statistically significant at the 1 percent level). As shown in the maps, the major differences between both programs are observed in the participation components. "Spatial scale of R&D linkages highly depends on the degree of codification and the nature of the knowledge being exchanged (basic vs. industrial and mutually purposeful knowledge)" (Bergé, Wanzenböck, and Scherngell, 2017:166).

4.2 Networks and competitiveness

The results of the estimations to assess the links between regional competitiveness and ICT knowledge networks are presented in Tables 2 and 3. As to the FP7-ICT, the coefficient of the BC-related score is positive and statistically significant for both the RCI and its components. Hence, the higher the centrality of a region in terms of its bridging paths in the FP7-ICT research network, the higher its competitiveness. This result highlights the importance of regions that bridge paths, acting as intermediaries that canalize the flows of knowledge and information through the network. As Iturrioz, Aragón and Narvaiza (2015) indicate, intermediaries are necessary to develop a sustainable, systematic, and distributed innovation work as well as to obtain new and complementary knowledge which is beneficial for competitiveness. Moreover, this positive relation is observed with all the elements of competitiveness, from the basic conditions to the more innovative aspects. In the CIP-ICT network, bridging centrality has also a positive and statistically significant coefficient on the RCI. By components, it only matters for innovation issues and to a lesser extent for basic conditions. These results suggest that the links in EU-funded research and diffusion networks (and the corresponding knowledge, information and ideas flowing through them) are different and consequently have different implications for competitiveness. Through the research links established in the FP7-supported network, regions access to new and complementary knowledge, information, ideas that are beneficial to competitiveness by strengthening each of its elements. In contrast, knowledge flows in diffusion networks reinforce competitiveness mainly through the innovation channel. Research networks have effects over competitiveness on a wider scope than those of diffusion networks. This might be related, at least to some extent, to the fact that different types of organizations, with different pools of knowledge and resources, were involved in the networks: the FP7 included both large firms and SMEs, higher education institutions, research centers, public institutions, etc.; this implies a much-varied pool of knowledge than that of the CIP, that targeted SMEs.

Table 2. Estimates for regional competitiveness (FP7-ICT). Coefficients and standard deviations

VARIABLES	RCI (1)	RCI (2)	BASIC (3)	BASIC (4)	EFFICIENCY (5)	EFFICIENCY (6)	INNOVATION (7)	INNOVATION (8)
BC_SCORE _{FP7}	0.475*** (0.128)		0.340*** (0.089)		0.389** (0.173)		0.731*** (0.148)	
PARTICIPATION _{FP7}		0.456*** (0.141)		0.335*** (0.098)		0.378** (0.191)		0.669*** (0.164)
OUTWARD _{FP7}		-0.163 (0.424)		-0.092 (0.294)		-0.088 (0.572)		-0.464 (0.492)
DIVERSIFICATION _{FP7}		0.429 (0.302)		0.314 (0.209)		0.537 (0.408)		0.493 (0.350)
<i>Controls</i>								
GDP	0.500*** (0.063)	0.494*** (0.064)	0.251*** (0.043)	0.245*** (0.045)	0.640*** (0.084)	0.626*** (0.087)	0.517*** (0.072)	0.524*** (0.075)
R&D	0.035*** (0.011)	0.033*** (0.011)	0.021*** (0.008)	0.019** (0.008)	0.022 (0.015)	0.018 (0.015)	0.071*** (0.013)	0.069*** (0.013)
HKAPITAL	0.014*** (0.003)	0.015*** (0.003)	-0.004 (0.002)	-0.004 (0.002)	0.019*** (0.004)	0.019*** (0.004)	0.019*** (0.004)	0.019*** (0.004)
Constant	5.323*** (0.628)	-5.514*** (0.661)	-2.338*** (0.436)	-2.482*** (0.458)	-6.823*** (0.848)	-7.099*** (0.892)	-5.723*** (0.726)	-5.835*** (0.767)
Observations	245	245	245	245	245	245	245	245
R-squared	0.943	0.944	0.973	0.973	0.897	0.898	0.943	0.943

Table 3. Estimates for regional competitiveness (CIP-ICT). Coefficients and standard deviations

VARIABLES	RCI (9)	RCI (10)	BASIC (11)	BASIC (12)	EFFICIENCY (13)	EFFICIENCY (14)	INNOVATION (15)	INNOVATION (16)
BC_SCORE _{CIP}	0.195** (0.097)		0.116* (0.066)		0.050 (0.131)		0.522*** (0.107)	
PARTICIPATION _{CIP}		0.241** (0.119)		0.146* (0.080)		0.112 (0.159)		0.555*** (0.131)
OUTWARD _{CIP}		0.745 (0.868)		0.786 (0.587)		0.991 (1.166)		0.539 (0.957)
DIVERSIFICATION _{CIP}		0.046 (0.362)		0.302 (0.245)		-0.286 (0.487)		0.568 (0.399)
<i>Controls</i>								
GDP	0.491*** (0.070)	0.494*** (0.071)	0.241*** (0.048)	0.239*** (0.048)	0.648*** (0.094)	0.659*** (0.095)	0.475*** (0.077)	0.469*** (0.078)
R&D	0.026** (0.012)	0.025** (0.012)	0.014* (0.008)	0.011 (0.008)	0.007 (0.016)	0.008 (0.016)	0.070*** (0.013)	0.066*** (0.013)
HKAPITAL	0.020*** (0.003)	0.020*** (0.003)	0.001 (0.002)	0.001 (0.002)	0.026*** (0.005)	0.026*** (0.005)	0.022*** (0.004)	0.022*** (0.004)
Constant	-5.280*** (0.705)	-6.093*** (1.158)	-2.276*** (0.480)	-3.309*** (0.783)	-6.968*** (0.949)	-7.784*** (1.556)	-5.331*** (0.780)	-6.339*** (1.277)
Observations	224	224	224	224	224	224	224	224
R-squared	0.943	0.943	0.974	0.974	0.899	0.899	0.946	0.947

In addition, the content of the networks was different: basic and applied research including diffusion in the FP7 and, just diffusion, aimed at innovation and competitiveness, in the CIP.

When the BS score is disaggregated by its three components (participation, outward orientation, and link diversification), only participation is statistically significant and with positive signs in both the FP and CIP networks. This suggests that regional competitiveness is mainly associated with the breath of the network, i.e., with the number of external links. Hence, the higher the number of external ties, the higher the regional competitiveness. In this sense, several authors highlight the importance of non-local research relationships since they help to avoid regional lock-in via the complementary capabilities of other regions (Miguelez and Moreno 2018; Tavassoli and Carbonara 2014). The non-significant result of diversification is in line with some recent evidence that shows that external knowledge flows have a higher impact, the higher the similarity between these flows and the extant local knowledge base (Miguelez and Moreno 2018). Through these knowledge flows, regions can modernize their industries or move into new but related industries which results in higher levels of competitiveness (Balland et al. 2018). Our results indicate overall that “being highly connected to the outer world” is what matters for competitiveness.

Finally, we notice that R^2 in all our estimated regressions is very high. The reason is the inclusion of country dummies. If we drop them from the estimations, R^2 is between 65 and 75%. We have also checked for potential multicollinearity problems. Table A1 in Annex shows Variance Inflation Factors (VIFs). Only the VIF for GDP is a bit over the threshold of 10 and could indicate the existence of some multicollinearity. If GDP is dropped, the BC-related variables keep their statistical significance, but their coefficients largely increase which might suggest the existence of some omitted variables bias. Some robustness checks have been run. Overall, their results support the above-mentioned relationships of the BC score with competitiveness across all its dimensions for the FP7-ICT; and for the CIP-ICT, with the innovative component.⁶

⁶ The results from the estimations without the variable GDP and robustness analysis are available from authors upon request.

5. Conclusions and Discussion

The strengthening of competitiveness is a critical goal of the European research and innovation policy. The creation and extension of collaborative research networks have been revealed as a key driver for knowledge creation and knowledge spillovers that are sources of regional competitiveness. Using Social Network Analysis and the bridging centrality, a novel measure of the position of a node in a network, we have examined the existing internal and interregional links generated in the research networks created by the 7th Framework Program (FP7) and the ICT action of the Competitiveness and Innovation Framework Program (CIP). In addition, we have analyzed the impacts of the links created on regional competitiveness employing a recent measure of regional competitiveness, the Regional Competitiveness Index developed by the European Commission. Unlike other indicators that measure productivity, the Regional Competitiveness Index considers a wide range of socio-economic factors that allows us to assess whether the effects of European-funded ICT research and diffusion networks go beyond purely economic aspects.

Centrality analysis points out the roles of regions in the diffusion of ICT knowledge. Results suggest that many regions have a limited ability to benefit from access to diversified knowledge or to exploit external knowledge. Although regions in general present a high openness to the research collaboration with others, they have failed to implement a diversified inter-regional research structure. Few regions present high diversification and then have the capacity to inhibit lock-in frameworks and renovate their regional knowledge assets. These regions are well-positioned to establishing international relationships through bridging paths. The academic literature demonstrates a strong concentration of some highly connected countries and regions showing a dichotomy core-periphery structure that is influenced by cultural and geographical factors (European Commission 2018; Wanzenböck, Scherngell and Lata 2015; Bergeé, Wanzenböck and Scherngell 2017; European Commission 2018; Scherngell 2019; Tóth et al. 2021).

Another finding is that, although the content and the type of organizations of each network are different, regions' capacities to access and diffuse valued knowledge flows seem to be the same in both. Thus, our analysis of regions' bridging centrality scores shows a

positive correlation between the two networks indicating that a region with a central position in the FP7-ICT project-based network is highly likely to be also central in the CIP-ICT one.

As for the effects of European ICT research and diffusion networks on competitiveness, both networks seem to be effective, as shown by the positive and statistically significant coefficients estimated for regions' bridging centrality scores on the regional competitiveness index values. Hence, regions with higher capacities to establish bridging paths tend to show higher levels of competitiveness. In contrast, those European low-urbanized regions should confront challenges not only to increase research and innovation activities but also to reduce social pressure and improve economic and environmental well-being. Moreover, the results indicate that these effects differ between research and diffusion networks, in other words, while both Programs fulfil their objectives in terms of competitiveness, their channels to competitiveness are different. In particular, the FP7 related network impacts all the dimensions of competitiveness, while the CIP influences competitiveness only through the innovative channel. While the CIP-related effect might be considered modest compared to the FP7, it is important to consider that CIP goals focused specifically on boosting innovation and competitiveness. Thereafter, we could affirm that the CIP has accomplished their objectives. So has the FP7, a program of a wider scope which aimed to have broad economic and social effects.

Some policy implications can be drawn from our findings. As mentioned before, BC scores are highly correlated between the networks, pointing out that regions in peripheral positions are the same in both networks. That indicates that there is not an effective exchange of information and knowledge neither between regions nor within countries. The results once again point to the European regional divide between knowledge-intensive regions and the less innovative ones. In this sense, public actions should promote the development of institutional actions and instruments that facilitate intra- and inter-regional collaboration networks. It would help the laggard ones to diversify their sources of knowledge. In particular, in the context of the Framework Programs, the European research and innovation policy should promote the collaboration between the more innovative regions and the less innovative ones to facilitate both the creation and recombination of knowledge as well as the development of knowledge spillovers, since there is evidence that regional innovation performance of leader regions positively impact on that of the laggard ones (De Noni et al.

2018). As for the links between network connectedness and competitiveness, public actions should be devoted to facilitating knowledge spillovers by acting on network characteristics, organizations' positioning and the nature of the links created. Besides, these actions should be complemented with other public initiatives that jointly consider the role played by different types of regions in the various R&D networks and the specific models of regional economic development and specialization (Capello and Cerisola 2019) to enhance regional competitiveness in Europe.

It should be noted that our analysis presents some limitations. First, we assess the effects of EU networks on competitiveness at a macro level. Micro-level analyses and case studies would have allowed us to better capture, identify and understand the mechanisms through which network connectedness and knowledge flows influence competitiveness. Hence, our analysis should be considered as supplementary of micro-level and case studies. Second, to analyze the effects of EU networks on competitiveness, we have used cross-sectional data, with the independent variables referring to previous periods of the dependent variable to take into account the lag effect between the investments in R&D and innovation and the realization of the benefits of such investments. As more data on the regional competitiveness index become available, it will be possible to better and properly assess the causal relationships between EU-supported knowledge networks and competitiveness.

To explore the effects of research and diffusion networks on regional economic performance further analysis should explore in more depth the collaborations and knowledge interactions among the several regional actors - business, universities, and public research centers - in the context of the EU Framework Programs. It would contribute to better identifying the nature of the links generated within and among regions and the role played by the knowledge intermediaries in the effects on the regional competitiveness. The analysis may also be expanded to include new sectors to compare the nature of the existing disparities in the links between laggard and leading regions at the sectoral level. Finally, as mentioned earlier, future studies should include a larger period of analysis as more data on the regional competitiveness index become available.

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Declaration of interest statement

No potential conflict of interest was reported by the author(s)

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Annex

Table A1. Variance Inflation Factors (VIFs)

	FP		CIP	
	(1), (3), (5), (7)	(2), (4) (6), (8)	(9), (11), (13), (15)	(10), (12), (14), (16)
BC_SCORE	1.59		1.79	
PARTICIPATION		1.76		2.17
OUTWARD		1.63		1.44
DIVERSIFICATION		1.48		1.27
GDP	10.54	11.12	11.93	12.05
R&D	1.91	1.97	1.9	1.98
HKAPITAL	5.95	6.01	5.56	5.64