European Commission

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Manuscript completed in November 2018.

Luxembourg: Publications Office of the European Union, 2018

PDF	ISBN 978-92-79-98160-9	doi:10.2777/651302	KI-07-18-066-EN-N

Dynamic Network Analysis of the EU R&I Framework Programme

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1 Introduction

A key EU Added Value of the EU Framework Programmes for Research and Innovation (R&I) consists in the creation of transnational and multidisciplinary networks (European Commission, 2017 and 2018). The Framework Programmes offer unique collaboration and networking opportunities between researchers. Collaborations within the network generate spillover effects and knowledge sharing while bringing the R&I effort in Europe closer to the critical mass required to tackle global societal challenges.

The majority of the Horizon 2020 budget is spent on supporting such collaboration through collaborative R&I projects. However, to fully reap the benefits of collaborative R&I, it is important that the network remains open and easily accessible to new participants. In this context, a good understanding of the way researchers collaborate within the Programme is crucial.

The interim evaluation of Horizon 2020 (European Commission, 2017) already provides several insights into the collaborations between researchers within the Framework Programme, based on publications (Elsevier, 2017) and project data. In particular, it suggests that collaboration patterns may have evolved between the 7th Framework Programme and Horizon 2020. Previous work also examined the evolution of the collaborations between the 6th and the 7th Framework Programme (Science Metrix, 2015; with 40% of the projects completed in FP7).

This paper explores further certain aspects of the collaborations between participants and provides additional evidence related the dynamic evolution of the network of participants to the Programme. The analysis covers the evolution since the Sixth Framework Programme of the national beneficiary entities in the participant networks. While the complexity of such a large network can be examined from different angles, this paper focuses on cross-country collaborations. In particular, the analysis highlights how the situation of entities has changed over the last decade.

The paper is based on monitoring data of Horizon 2020 and its predecessor programmes, the Sixth and the Seventh Framework Programme for Research and Technological Development (FP6 and FP7), covering the 2003-2017 period[1]. The data covers collaborative projects[2] launched during the first four and a half years of implementation of Horizon 2020, and the full implementation of FP6 and FP7[3]. The data is stored in the Common Research Data Warehouse (CORDA), an internal database maintained by DG RTD. For this paper, country groups (i.e. EU-15, EU-13, associated countries and third countries) are based on the situation in Horizon 2020.

2 The current network (static analysis)

2.1 Overview of the Horizon 2020 network

The size of the Horizon 2020 collaboration network is massive. Since 2014, Horizon 2020 has been funding a very large number of collaborative projects, which involved a massive network of collaborations between R&I stakeholders. Over 2014-2017, Horizon 2020 funded more than 7,500 collaborative projects among 23,664 participants from 149 countries, which results in almost 1.5 million of one-to-one

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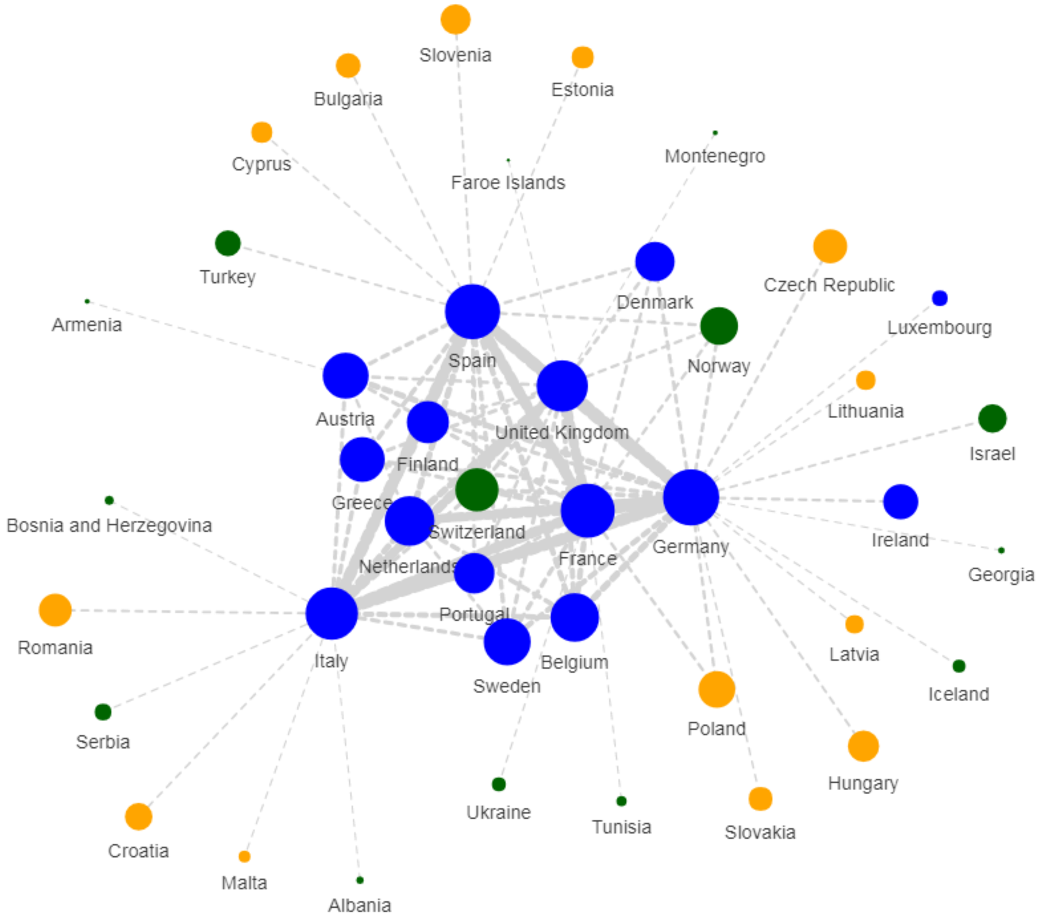
[1] Year of signature of the contract. Cut-off date for Horizon 2020 is 1/1/2018.

[2] Data include all evaluated calls for collaborative projects. Projects under Public-Public Partnerships, EIT's Knowledge and Innovation Communities (KICs) and direct actions of the Joint Research Centre are not included.

[3] Projects with incomplete data on signature date, duration and participant identifier were removed from the analysis (about 99.1% of the initial dataset of collaborative projects).

opportunities to collaborate[4]. The strongest connections that emerged out of Horizon 2020 are represented as a country-country graph in Figure 1.

Figure 1 The H2020 Collaboration Network.



Note: This graph represents the backbone of Horizon 2020. Nodes are countries, and links represent strong[5] connections based on Horizon 2020 projects. EU-15 countries are represented in blue, EU-13 countries are represented in orange, Associated Countries (AC) are represented in green. Third countries (TC) countries are not represented on the graph. Source: Author's calculations based on CORDA data.

The figure shows two types of connections: (i) the single strongest connection of each country to another country, and (ii) the top 40 strongest connections in the network. Centrality can be defined as the importance of a country in the network. This importance as such can have different meanings, hence different definitions, with the most straightforward definition being based on the number of connections of a country's participants in the whole network. The size of the nodes is proportional to the centrality of the country. The figure shows that **the core of the network is mainly composed of EU-15 participants.** Germany, France, the UK, Italy, and Spain appear to be key players in the network of participations to Horizon 2020.

[4] Before Horizon 2020, FP6 and FP7 funded respectively 5,912 and 12,493 collaborative projects, which correspond to 1,305,305 and 1,989,450 collaborations between participants.

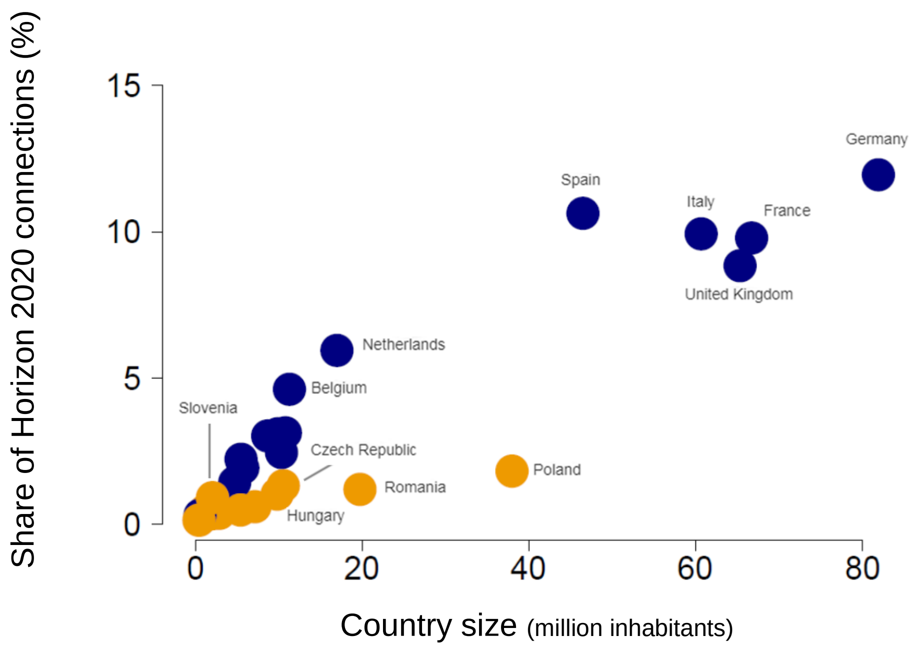
[5] Links displayed on this graph with N actors combines the N-1 links of a maximum spanning tree (MST) and the N-1 strongest links of the original graph. The MST represents the backbone of a weighted network and is based on three rules. First, only N-1 links from a network with N actors are kept. Second, rule #1 should be satisfied while keeping the strongest links. If xij = 1, xjk = 2, and xki = 3, the algorithm will remove xij. Third, rule #1 and #2 should be satisfied without creating any isolate in the network.

EU-13 participants have a substantial number of collaborations with the largest players in the network, which are participants from EU-15 countries. As a result, German participants are frequent partners of several EU-13 countries, such as Czech Republic, Hungary, Latvia, Lithuania and Slovakia. Croatia, Malta and Romania present strong ties with Italy, while Bulgaria, Cyprus, Estonia and Slovenia tend to connect with Spanish participants. Important collaborators of Polish participants are French participants.

2.2 Which country groups are the most central?

It is important to understand which countries occupy central positions in the network – are better connected with other countries. Overall, as shown in the interim evaluation of Horizon 2020 (European Commission, 2017), **the most connected countries are also the largest ones** (Figure 2). The most connected country is Germany, with around 12% of the collaborations within the network involving German participants, followed by Spain (11%), Italy (10%), and France (10%). Overall, 79.3% of the collaborations involve participants from EU-15 countries against 9.8% for EU-13 countries (and respectively 6.6% and 4.2% for associated and third countries). Poland is the EU-13 country with most connections (1.8% of all connections).

Figure 2 Country size and share of connections under Horizon 2020



Source: Author's calculations based on CORDA data.

While size effect appears to be important, Figure 2 also shows that **some countries with similar size perform differently in terms of collaborations**: although population in Romania and the Netherlands are close, Dutch participants are responsible for a much higher share of connections in the Programme (6%) than Romanian participants (1.2%). On the other hand, smaller countries like Slovenia present almost as many connections as countries with a population that is five times larger or more like Hungary, Czech Republic and Romania. The graph also highlights a significant gap between Poland and Spain, with Spanish participants being involved in almost four times more collaborations than Polish participants despite the fact that both countries have a large population.

Box 1 Methodology: what is centrality in a network?

Centrality can be defined as the importance of a node (here a participant) in the network. This importance as such can have different meanings, hence different definitions. Using data on Framework Programmes' project participations, a network of participants was constructed, represented by an $n \times n$ matrix $X = (x_{ij})$, where x_{ij} represents the number of connections between participant i and participant j $(i, j = 1, \ldots, n)$. The **positions of participants** are analysed in this global network using four different metrics: degree centrality, eigenvector centrality, network hubs, and EU15-EU13 gatekeeping position:

- **Degree centrality** refers to the number of direct connections of a given node. Degree is a simple and effective measure of the importance of a node in a network and can be computed as follows: $\boldsymbol{Degree_i} = \sum_j \boldsymbol{x_{i,j}}$

- **Eigenvector centrality** is a more complex measure of centrality that takes into account the centrality of participants a participant is connected to. Eigenvector centrality takes into account the whole network structure, and is equal to the leading eigenvector of the column stochastic $n \times n$ matrix $X = (x_{ij})$ - whose leading eigenvalue is 1: $\boldsymbol{Eigen_i} = \sum_j \boldsymbol{X_{i,j} x_j}$

- **EU15-EU13 gatekeeping positions** are derived from betweenness centrality and reflects the number of times a given participant i connects an EU-15 participant j with an EU-13 participant k (i.e. the number of times i lies on the shortest path between EU-15 and EU-13 participants. Let's $\sigma_{j,k}$ be the total number of shortest paths from node j (EU13) to node k (EU 15), and $\sigma_{j,k}$ (i) the total number of shortest paths from node j (EU13) to node k (EU 15) that passes through i. The EU15-EU13 gatekeeping position can be computed as $\boldsymbol{GatekeepingEU13 - EU15_i} = \sum_{j \neq i \neq k} \frac{\sigma j,k\,(i)}{\sigma j,k}$. This paper presents the *share* of EU15-EU13 gatekeeping positions, which is obtained by dividing $\boldsymbol{GatekeepingEU13 - EU15_i}$ by $\boldsymbol{Gatekeeping_i}$ (overall gatekeeping).

- **Network hub** is a dummy variable (0/1) that takes the value 1 if a participant belongs to the top 2% of both the degree and eigenvector centrality distribution.

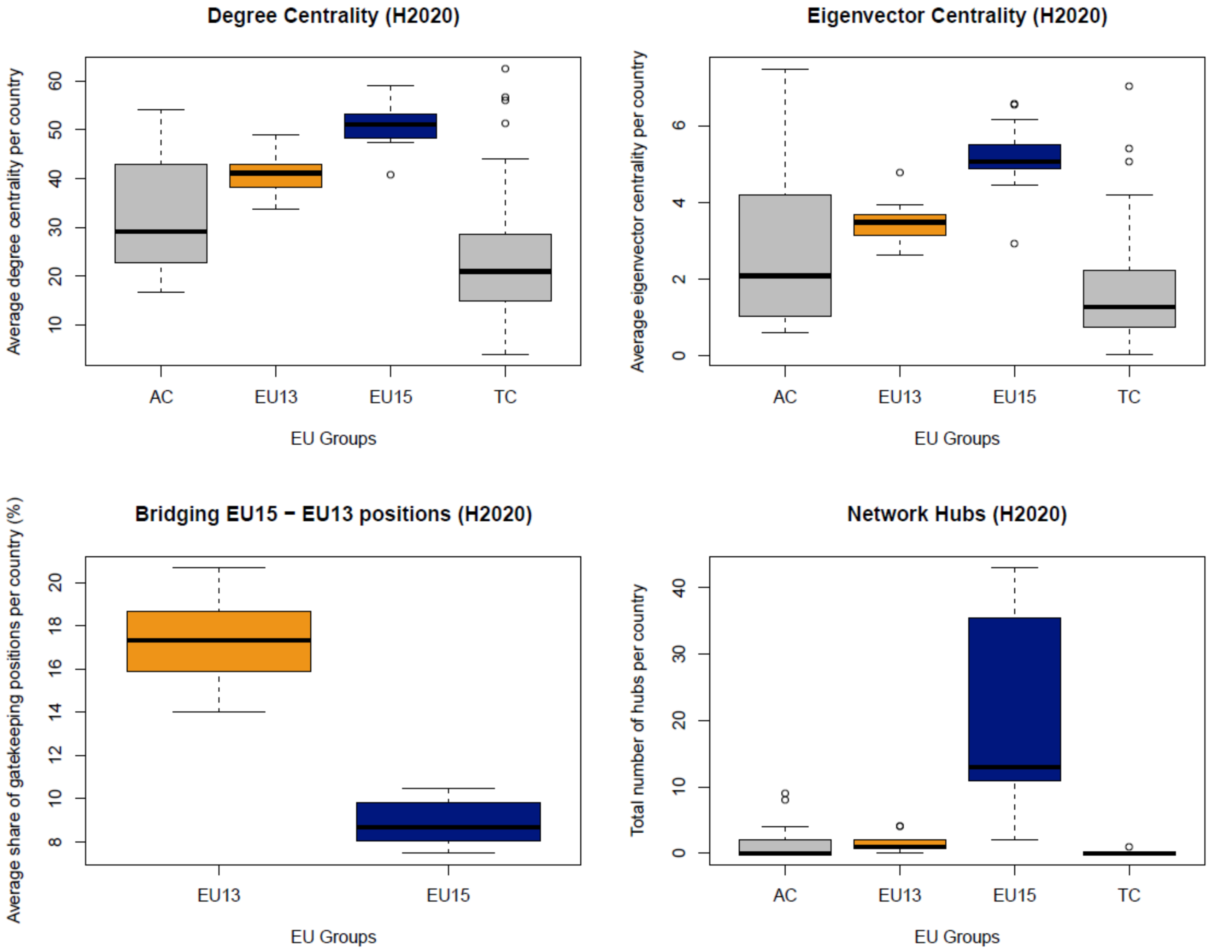
The position of countries can be more precisely assessed with different centrality measures (see Box 1). In Horizon 2020, **centrality measures show that participants from EU-15 countries tend to be more central than participants from EU-13 countries, associated countries and third countries in Horizon 2020** (Figure 3). **There are, however, important variations, with some EU-13 participants being more central than many EU-15 participants**. Both in terms of degree centrality (number of direct connections) and eigenvector centrality (tendency to be linked to nodes that are themselves central), participants from EU-15 countries appear to be on average more central than participants from other country groups[6]. The **average degree centrality** of EU-15 participants is 50, compared to 41 for EU-13 participants, 42 for participants from associated countries and 28 for participants from third countries, which indicates more direct connections for EU-15 participants. The influence of a country in the network can also be measured by examining whether participants are linked to other important participants (i.e. participants with many connections). This is measured by the **eigenvector centrality[7]**, which is again significantly higher on average for EU-15 participants (5.33) compared to EU13 countries (3.52).

Participants from associated countries and third countries are on average less central than EU participants based on both centrality measures. Participants from associated countries and third countries present an average degree centrality that is significantly lower than for EU participants. Eigenvector centrality measures lead to a similar conclusion, with an average value of 4.67 for participants from associated

[6] The interim evaluation of Horizon 2020 also shows highest centrality measures for EU-15 countries in Horizon 2020 compared to other country groups. The approach used for country analysis in this interim evaluation relies on connections at country level after aggregation of participants, not average statistics of participants within a country as in this analysis. As a consequence, differences in centrality measures seem to be exacerbated at participant level in this paper, especially the difference between EU-15 countries and EU-13 countries.
[7] The maximum value for the eigenvector centrality of a participant is 1. To avoid very small values when we average eigenvector centrality of participants at the country level, we multiply eigenvector centrality by 1,000.

countries and 2.12 for participants from third countries. These country groups are also more heterogeneous: the distribution of centrality measures is much more dispersed for these country groups compared to EU-15 and EU-13, with some participants showing very high average centrality while others present low centrality measures. Within third countries, the United States and China stand out as the most central countries (see Annex for centrality measures for all countries).

Figure 3 Centrality measures in Horizon 2020[8]



Note: All network measures are first computed at the participant-level, and then summed up/averaged at the country level. The boxplots in this figure show the distributions of these measures at the country level (thick line = median, limits of the box = interquartile interval, upper and lower whiskers = greatest and lowest values excluding outliers). Degree centrality, for instance, represents the distribution of the average degree centrality of participants at country level. Source: Author's calculations based on CORDA data.

While EU-15 participants are more frequently playing a role of hub in the network, critical intermediaries between EU-13 and EU-15 participants are more represented by EU-13 organisations. Most network hubs (participants that have a significantly larger number of connections in the network) are EU-15 participants. However, key gatekeeping positions are much more present within EU-13 participants compared to EU-15 participants. This means that EU-13 organisations very often act as a bridge between EU-15 organisation and EU-13 organisations. This result is not surprising because EU-15 countries participate more than EU-13 countries. Hence, the likelihood to have one EU-13 participant in a project with a majority of EU-15 participants is higher than the other way around. This highlights that EU13 organisations have a 'broker' or 'gate-keeper' role for linking a large number of organisations that would not be

[8] These measures are based on the network of participations without any threshold in the number of connections between two participants. See Annex for centrality measures based on connections in at least 2 projects.

connected otherwise. Slovakia, Latvia, Malta, and Estonia are the top 4 countries in which participants have the strongest gatekeepers profile between EU-13 and EU-15 participants.

2.3 What are the differences between types of organisations?

As shown in Table 1, higher education institutions are the real hubs of the network in general. They present significantly higher centrality measures compared to other types of participants, in particular a very high average degree centrality of 144 compared to 87 for research organisation, 42 for public bodies and 29 for privates companies. Many higher education institutions also play the role of hubs in the network: 233 hubs universities under Horizon 2020, which is more than all other types of participants together. Research centres seem to be the second more central type of organisation, followed by public organisations.

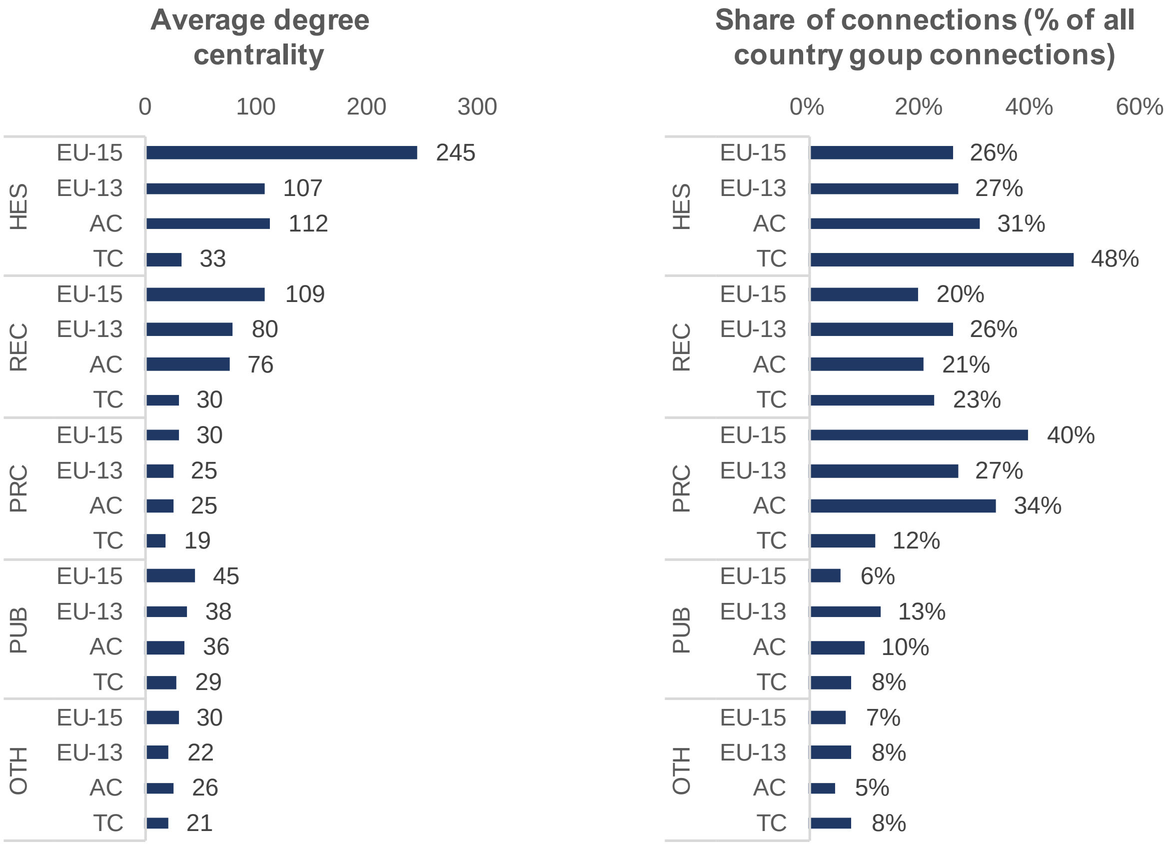
Table 1 Network statistics by type of organisation (Horizon 2020)

Type of organisation	Average Degree centrality	Average Eigenvector centrality	Average share of gatekeepers EU-13-EU15	Total number of Hubs
Public bodies	41.5	3.1	0.13	9
Higher education	144.4	19.5	0.11	233
Research organisations	87.4	11.1	0.11	93
Private companies	29.1	2.3	0.08	25
Other	28.3	1.7	0.11	3

Source: Author's calculations based on CORDA data.

On the other hand, **private companies report low centrality measures**, which means that they are not as central as other types of organisations. This contrast with their significantly **large number of connections compared to other types of organisations.** Figure 4 illustrates this. The figure shows that 40% of the connections of EU-15 include private companies. The private sector is actually the most important sector in terms of number of collaborations for all country groups, except for third countries where higher education institutions are responsible for almost half the connections within the network. However, private companies are also characterised by a larger number of one-shot collaborations. As a consequence, they present particularly low average centrality measures compared to other types of organisations, especially compared to higher education institutions. Another important observation is that **the centrality of private companies in the whole network is similar between EU-15 countries, EU-13 countries and associated countries, while the centrality of higher education institutions in the EU-15 countries is significantly larger than in other country groups**.

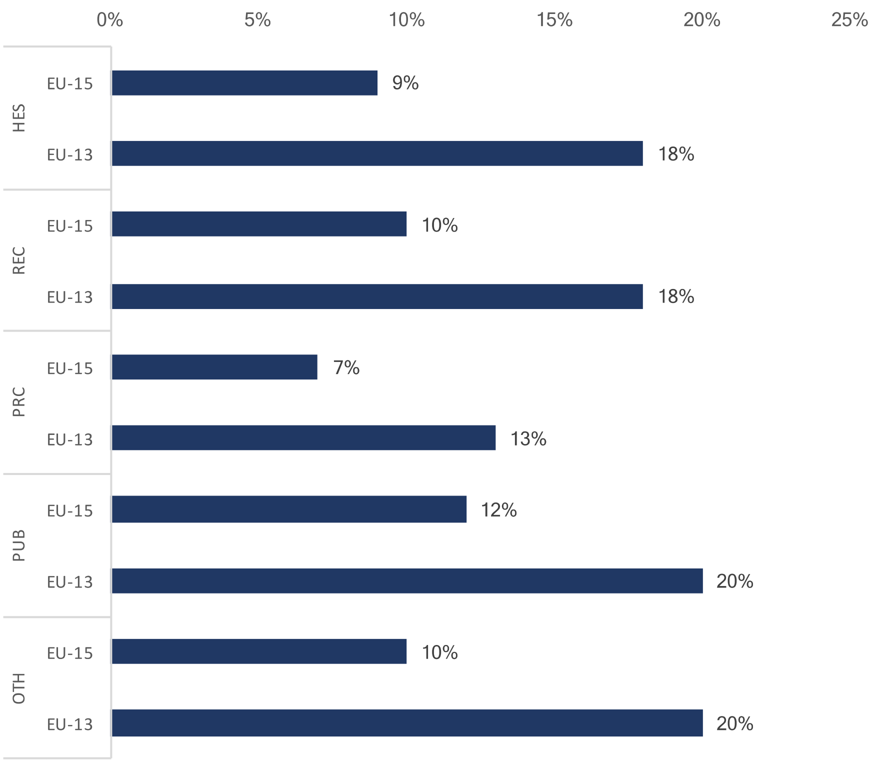
Figure 4 Centrality by type of organisation and by country group (Horizon 2020)



Note: REC = research organisations, PUB = public bodies, PRC = private sector, HES = higher education institutions, OTH = other participants. AC = associated countries, TC = third countries. Source: Author's calculations based on CORDA data.

When looking at collaborations between EU-13 and EU-15 participants (Table 1)**, participants acting as intermediaries ('gatekeepeers') are more frequent within public bodies (13%) compared to other types of organisations**. Only 8% of companies play this bridging role. Hence, while the interim evaluation of Horizon 2020 (European Commission, 2017) showed that EU-15 companies can represent significant numbers of connections with EU-13 participants, corresponding to massive bridges with EU-13 participants, this 'broker' role is not as frequent for them as for other types of participants. As abovementioned, this bridging role is much more frequent within EU-13 participants. Figure 5 shows the differences in this role by type of participant for EU-13 and EU-15 countries. EU-13 participants are almost always twice more active in this gatekeeping role than EU-15 participants, regardless of the type of organisation. At the bottom, only 7% of EU-15 private companies are bridging EU-15 and EU-13 participants. The most active gatekeepers are EU-13 research organisations, public bodies and higher education institutions (20%).

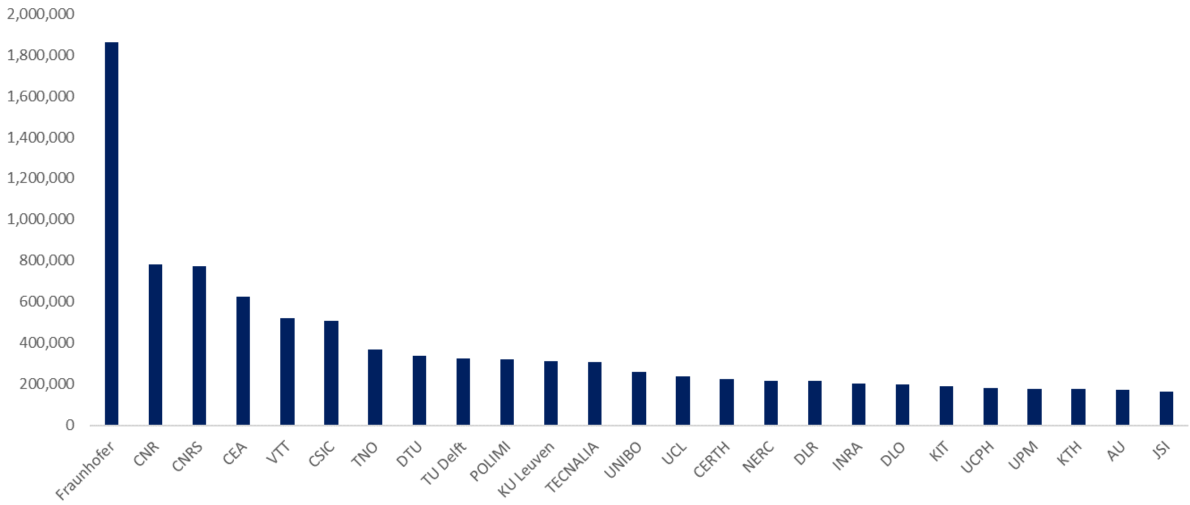
Figure 5 Bridging EU-15 - EU-13 positions (share of gatekeeping positions by type of organisation and country group)



Note: REC = research organisations, PUB = public bodies, PRC = private sector, HES = higher education institutions, OTH = other participants. Source: Author's calculations based on CORDA data.

At the participant level, the top EU-15 participants that present the largest numbers of collaborations with EU-13 participants in Horizon 2020 are presented in Figure 6. **Fraunhofer (DE), CNR (IT), CNRS (FR), CEA (FR) and VTT (FI) are the most important actors in terms of bridging EU-15 and EU-13 countries.** This is also related to the large participation of these organisations in the Programme. From a more relative perspective, top 5 EU-15 participants that present the highest share of collaborations with EU-13 participants in their collaborations are ENEA (IT), NERC (UK), CINECA (IT), UoA (EL) and JUELICH (DE).

Figure 6 Top EU-15 organisations bridging EU-15 and EU-13 participants (number of gatekeeping positions with EU-13 countries)

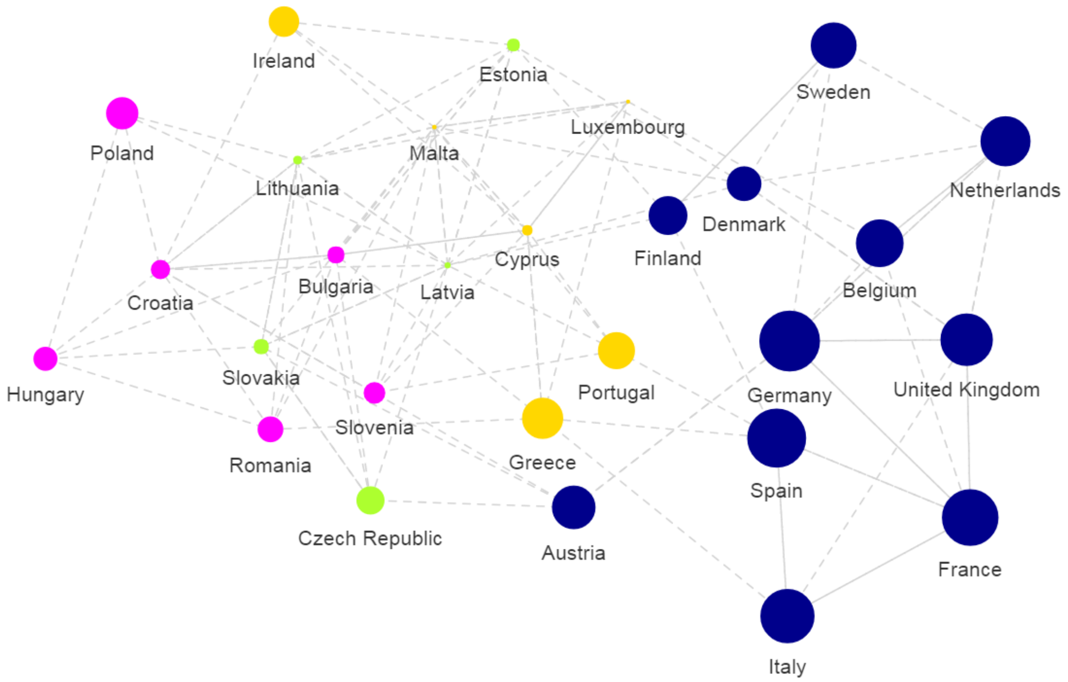


Source: Author's calculations based on CORDA data.

2.4 Do countries prefer to collaborate with specific countries?

The large number of connections between EU-13 countries and a few EU-15 countries can be partly explained by the larger number of participations of these EU-15 countries in Horizon 2020. A normalisation process can be implemented to control for this. Figure 7 shows the **country relatedness network**, which expresses collaboration preferences between countries. To compute this relatedness, the number of connections between two countries is divided by the number of connections expected by chance[9], i.e. based on the amount of participations of both countries (Hidalgo et al., 2007; Hidalgo et al., 2018; Balland et al., 2018). In Figure 7, the top four strongest connections of each country are represented. As a result, participants appear to show very specific preferences in their cross-country collaborations. Several clusters of countries can be observed[10]. Countries in a same cluster of strong preferences are represented by the same colour. Participants from Baltic countries, Czech Republic and Slovakia tend to collaborate more with each other than what would be expected statistically (green cluster). Cyprus, Greece, Ireland, Luxembourg, Malta, and Portugal form another group of preferred connections (yellow cluster). These two groups bridge to some extent the other two clusters, which are formed respectively by large EU-13 countries (pink cluster) and large EU-15 countries (blue cluster). **Overall, these preferences show that different forms of proximity, including cultural and geographical proximities tend to shape the structure of the Horizon 2020 network**.

Figure 7 The H2020 Country-Relatedness Network (between EU15 and EU13 countries)



Note: Colours based on community structure (Blondel et al, 2008). The top four strongest connections (after normalisation) of each country are represented. A plain link indicates that the connection is in the top four connections of both countries. A dashed link indicates that the connection is in the top four of one of both countries. The size of the nodes is proportional to country centrality without normalisation. Source: CORDA data.

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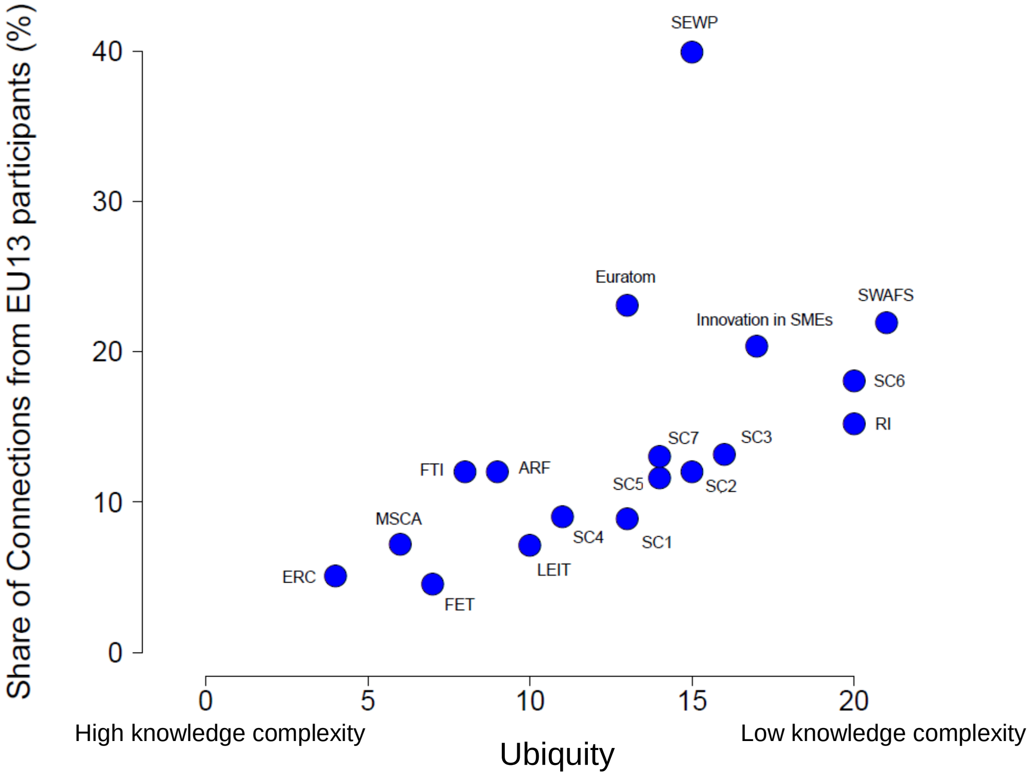
[9] Relatedness is computed using the EconGeo software, implemented as a R package (Balland, 2017).

[10] Communities within the network are based on the multi-level modularity optimisation algorithm for finding community structure as described by Blondel et al. (2008).

2.5 Do centrality patterns vary by programme parts?

Not all countries participate in the same proportion in the different parts of the Programme. This proportion directly affects the importance or centrality of a specific country in the different programme parts (see Annex for definition of the acronyms and for the number of connections by country and by programme part). Figure 8 shows that there is a pattern that can be observed when linking the ubiquity of the programme parts (parts that are more 'common' amongst countries, see Box 2) with the proportion of connections from EU-13 participants. Ubiquity has been shown to reflect the underlying knowledge complexity of products and technologies, and could therefore be interpreted as a measure of how difficult it is for a country to be a leader in a specific programme part. The figure shows that EU-13 and EU-15 participants are not central in the same programme parts. **EU-13 participants are much more central in programme parts with a lower level of knowledge complexity** (i.e. presenting high level of ubiquity), while EU-15 participants dominate more complex programme parts.

Figure 8 Ubiquity of programme parts and EU-13 centrality (Horizon 2020)



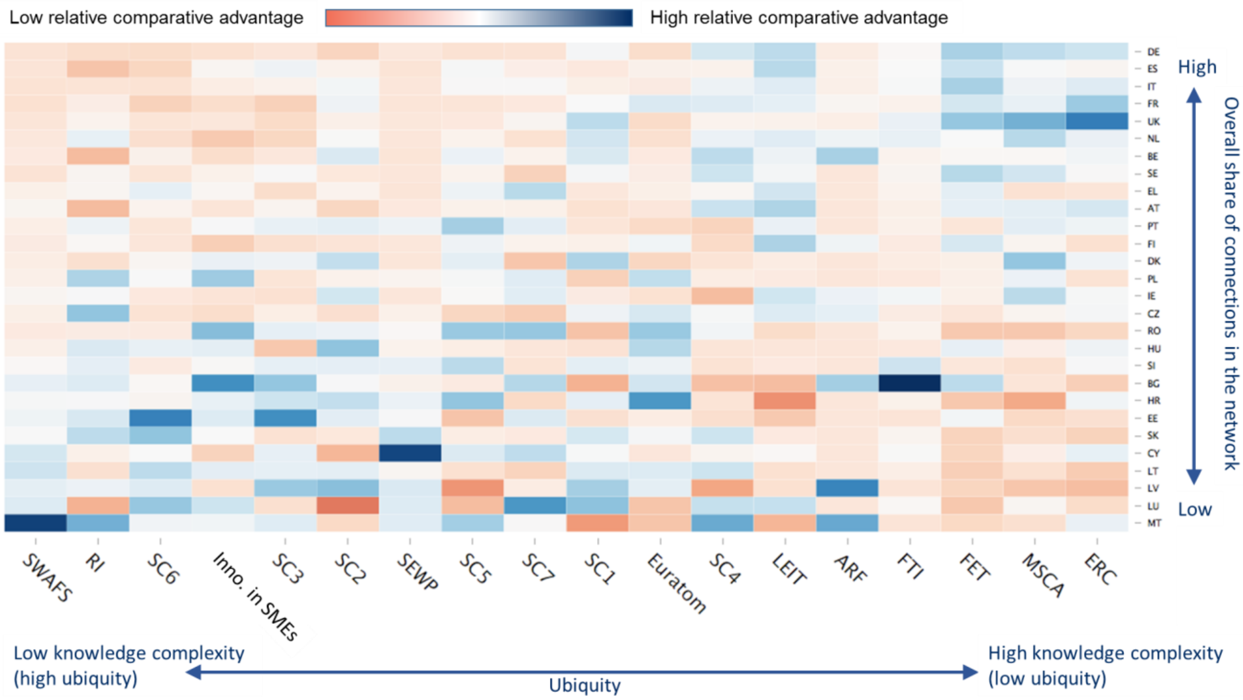
Note: Acronyms for programme parts in Annex. Some programme parts like ERC or MSCA only present a minority of projects with collaborations. Source: Author's calculations based on CORDA data.

Box 2 Methodology: ubiquity

Ubiquity refers to the number of countries that have a relative comparative advantage in a specific programme part. Relative comparative advantage is a measure of specialisation, i.e. a participant participates more than what could be expected by chance (Hidalgo and Haussman, 2009; Balland and Rigby, 2017). The country–project FP networks are operationalized as a n x k two-mode matrix M = (Mc,i), where Mc,i reflects whether a country c has a relative comparative advantage (RCA) in the participation of programme part i (c = 1,. . ., n; i = 1, . . ., k). A country c, has RCA in programme part i at time t if the share of projects i in the country's portfolio is higher than the share of projects i in the entire FP portfolio. Ubiquity is the 2-mode degree centrality of programme parts (Ki,0) and is given by the number of countries that exhibit RCA in a particular programme part: $\mathbf{Ubiquity_i} = \sum_c \mathbf{M_{c,i}}$.

The level of economic complexity reflects the fact that only few countries have a relative comparative advantage in the participation of a programme part. Figure 9 shows the relative comparative advantages of countries by programme parts when countries are ranked by decreasing overall centrality (share of connections) from top to bottom, and programme parts are ranked increasing complexity from left to right. The pattern of colours indicates that high relative comparative advantages (blue) can be found in the top right and bottom left parts of the matrix, while lower relative comparative advantages (red) dominate the top left and bottom right parts. This reflects the idea that countries that are less central are also countries that have a lower relative comparative advantage in more economically complex programme parts and higher comparative advantage in less complex programme parts.

Figure 9 Relative comparative advantage of countries by programme part (Horizon 2020)



Note: Acronyms for programme parts in Annex. Blue indicates high comparative advantage and red indicates low comparative advantage. Darker blue or red indicate respectively higher or lower values. Source: Author's calculations based on CORDA data.

3 Is the network more open in Horizon 2020 (dynamic analysis)?

As shown in the previous section, the size of countries in Horizon 2020 is a main determinant of their central position in the network. However, it is important to examine how the situation has evolved over time, between FP6 and FP7 and between FP7 and Horizon 2020.

3.1 Has the nature of collaborations changed?

On average, participants are slightly less central in the network in FP7 and Horizon 2020 compared to FP6. The average centrality degree of participants was 50 in FP6, while it became about 46 in FP7 and 47 Horizon 2020. This might signal the entry of smaller players, and indicate that the network tends to be opening to less connected participants. To confirm this intuition, we need to turn to other network indicators.

Box 3 Methodology: indicators for the structure of the network

Besides centrality measures (see Box 1), several indicators can help understanding the structure of a network. The following indicators can inform on the nature of the collaborations between participants:

- **Transitivity coefficient**: extent to which the relation that relates two nodes in a network that are connected by an edge is transitive.
- **Assortativity coefficient**: extent to which nodes in a network associate with other nodes in the network, being of similar sort or being of opposing sort. In this paper, the assortativity of the network is determined for the degree (number of direct neighbours) of the nodes in the network. If the assortativity coefficient is negative, the hubs tend to be connected with non-hubs, and vice versa.
- **Network inequality coefficient**: the Gini coefficient of the degree distribution. It ranges from 0 (perfect equality, with all participants having the same number of connections) to 1 (perfect inequality).
- **Average path length**: average number of steps along the shortest paths for all possible pairs of network nodes. It is a measure of the efficiency of information or mass transport on a network.

Participants appear to be more likely in Horizon 2020 than in FP7 to collaborate with partners of their own partners, i.e. the transitivity (see Box 3) of collaborations has increased. The likelihood for a participant to be connected to a collaborator of a collaborator is measured with transitivity coefficients. While the transitivity coefficient was around 0.12 in FP7, it has increased to 0.16 in Horizon 2020, indicating a significantly higher transitivity effect within the network of the last Framework Programme. This signals that participants rely more on the information that they receive from their own partners to create new collaborations, which could be reflected by higher clustering behaviours within the network.

Participant acting as hubs (i.e. with high degree centrality) also seem to connect more likely with other types of participants (non-hubs, with low degree centrality). This is illustrated by assortativity coefficients (see Box 3) that are negative for the 3 phases of the Framework Programme analysed. This suggests that key actors in the network have maintained a certain level of openness to other participants throughout the different programmes. However, the assortativity coefficient for Horizon 2020 (-0.08) is higher than for FP6 and FP7 (respectively -0.1 and -0.11), which indicates that assortativity in the network has been reinforced with Horizon 2020. This could be due to the fact that Horizon 2020 is only half-way and that less central organisations haven't been able to mobilise resources and join the network.

Network inequality coefficients are particularly stable over time. Network Gini coefficients (see Box 3) measure the level of structural inequality in the network, with one indicating perfect inequality and zero indicating perfect equality (all actors have exactly the same number of connections). The Network Gini coefficient indicates that the degree distribution has remained relatively similar between the Framework Programmes, with coefficient being 0.66, 0.67, and 0.65 respectively for FP6, FP7 and Horizon 2020. These coefficients suggest that few organisations have many connections, while most organisations have only a few, which is a general tendency of real-world complex networks. This aspect of the network has not been reinforced over time.

The average path length (see Box 3) between participants has remained close to 3, meaning that **on average a participant can be connected to any other participant in the network within 3 connections ("degrees of separation").** This measure is relatively small, indicating a highly-connected network in general. The average path length has not changed much over time.

Table 2 Evolution of the network

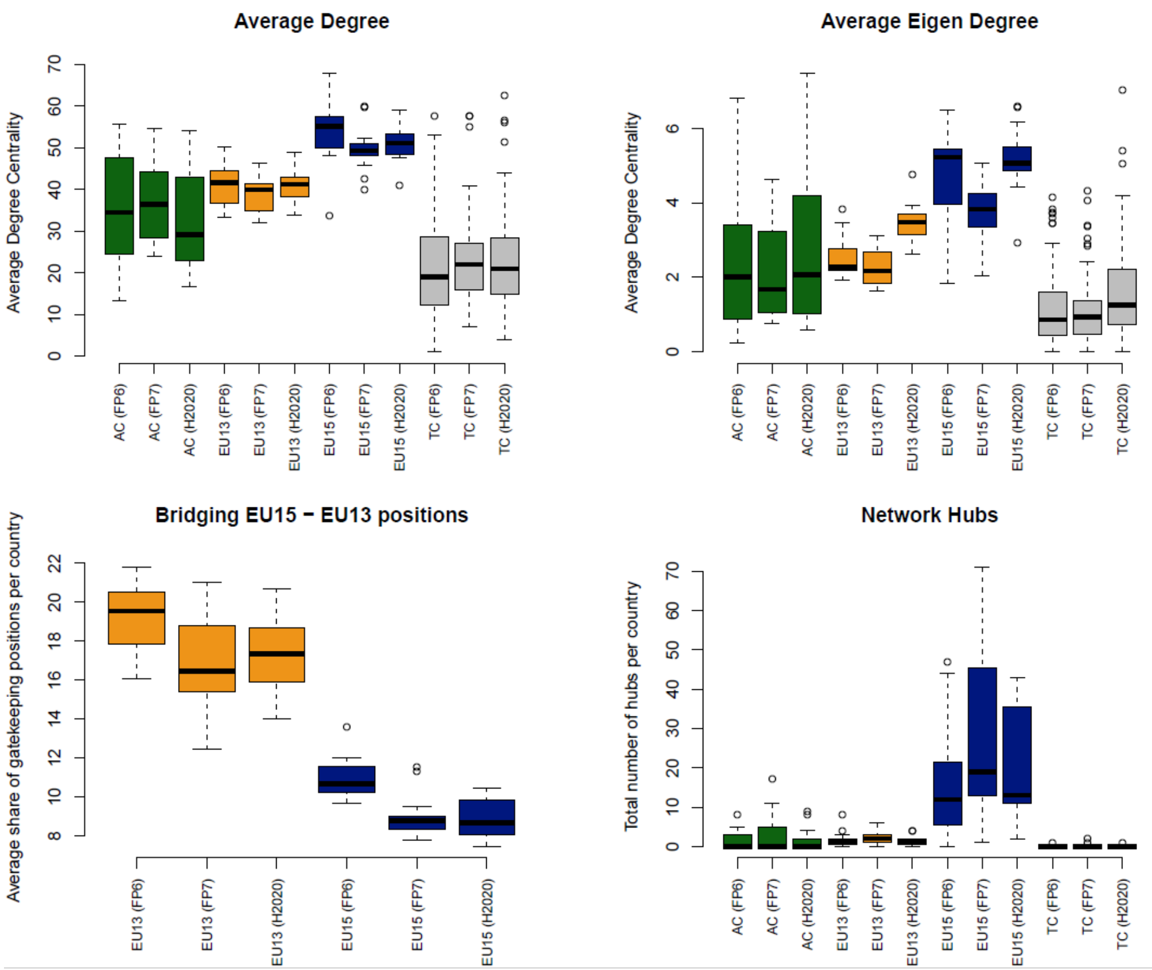
Framework Programme	Average degree centrality	Transitivity	Assortativity	Inequality	Average path length
FP6	50.22	0.17	-0.1	0.66	2.79
FP7	46.01	0.12	-0.11	0.67	2.79
Horizon 2020	47.06	0.16	-0.08	0.65	2.81

Source: Author's calculations based on CORDA data.

3.2 Has the position of country groups changed?

The centrality of country groups[11] has remained stable over time. Figure 10 shows little change in the ranking between country groups of average centrality measures between FP6 and Horizon 2020. Between FP6 and FP7, EU-13 and EU-15 participants seem to have become less central in the network, while the central position of participants from associated countries and third countries was reinforced (especially based on degree centrality). However, between FP7 and Horizon 2020, the centrality in the network of both EU-15 and EU-13 countries improved. Based on the number of hubs, the position of EU-15 countries appears to be less dominant in Horizon 2020 compared to FP7.

Figure 10 Evolution of centrality measures



Source: Author's calculations based on CORDA data.

[11] For this analysis, the composition of country groups does not vary over time. Country groups are defined based on the situation in Horizon 2020.

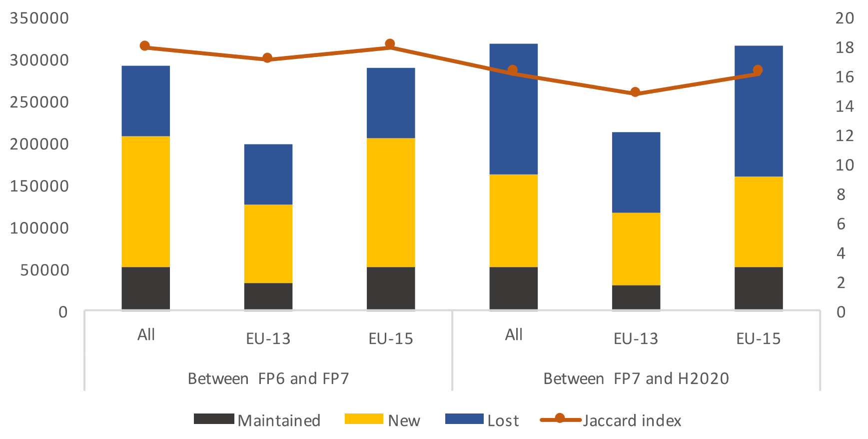
In order to look at the potential opening of the network over time, it is important to assess the persistence of the collaborations. A network that is structured in "closed clubs" will be characterised by a large amount of persistent collaborations, i.e. collaborations maintained over time, compared to new or lost collaborations. This can be measured by the Jaccard index (Ripley et al., 2016; see Box 4), which is used here to assess the similarity of the connections between FP6 and FP7, and between FP7 and Horizon 2020. A Jaccard coefficient of 1 indicates perfect stability (no changes from one Framework Programme's network to the next), while a Jaccard coefficient of 0 indicates that none of the connections made in one Framework Programme is repeated in the next one.

Box 4 Methodology: Jaccard index

In dynamic network analysis, the **Jaccard index** measures the structural distance between networks from one period to the next (Ripley et al., 2016). It is computed by using information on the number of new ties (Nnew), the number of lost ties (Nlost), and the number of ties maintained (Nmaintained) from one period to the next: $\frac{Nmaintained}{Nnew+Nlost+Nmaintained}$

The network of participations to the Framework Programmes seems to be very dynamic over time. Jaccard indexes (Figure 11) for FP6, FP7 and Horizon 2020 are quite low[12] (Ripley et al., 2016), which indicates that partners are highly likely to change over time (i.e. between Framework Programmes). Between FP6 and FP7, about new 1,226,970 connections between partners were created, while 166,508 connections were maintained and 772,822 were lost. Between FP7 and the first four years of Horizon 2020, 909,444 new connections were made, against 195,474 maintained and 1,198,004 lost. Because of this large ratio of new and lost connections in Horizon 2020 to maintained connections, Jaccard indexes are especially low in Horizon 2020 and suggest a more dynamic network compared to previous Framework Programmes.

Figure 11 Persistence of connections in the network (maintained, new and lost connections between Programmes)



Note: Left axis: number of connections. Right axis: Jaccard index (x100). All = all projects, EU-13 = all projects with at least 1 EU-13 organisation, EU-15 = all projects with at least 1 EU-15 organisation Source: Author's calculations based on CORDA data.

The network is also more dynamic for EU-13 countries than for EU-15 countries. Jaccard indexes are lower for EU-13 than for EU-15 countries, which shows that EU-13 countries participants have to some extent a higher propensity to be involved in new collaborations than participants from EU-15 countries. This effect is especially striking in Horizon 2020: participants from EU-13 countries have managed to generate a relatively large amount of new collaborations compared to EU-15 participants. However both

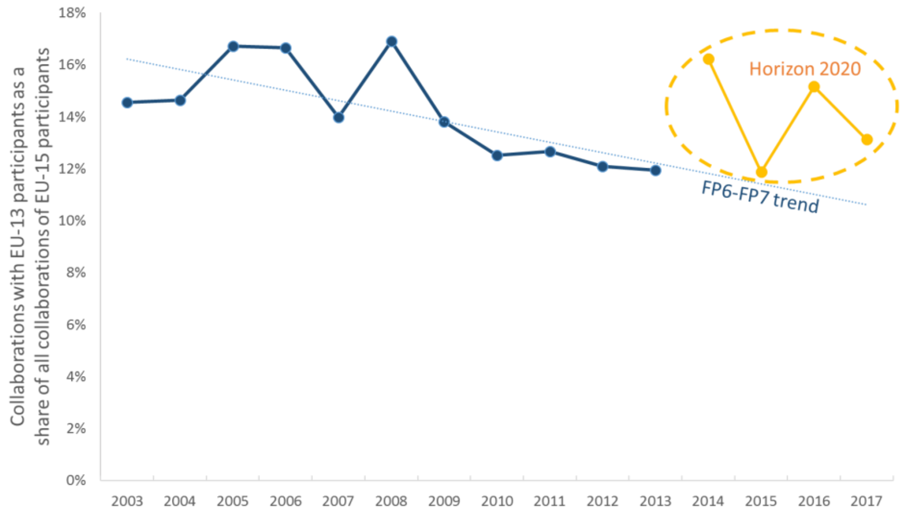
[12] Compared to other types of network in Ripley et al. (2016).

country groups seem to be opening more to new collaborations between FP7 and Horizon 2020 than between FP6 and FP7.

3.3 In particular, are EU15 countries opening up to EU13 countries?

While EU-15 participants seem to have been closing to some extent their collaborations to EU-13 participants between FP6 and FP7, they appear to have opened up to EU-13 participants with Horizon 2020 (Figure 12). In FP6, the percentage of connections between EU-15 participants and EU-13 participants was 14.4% of all collaborations from EU-15 participants. While this percentage decreased to 13.3% during FP7, it increased again to 13.7% in Horizon 2020. Hence, while the opening of EU-15 countries to EU-13 countries seems to have worsened during FP7, the situation has improved with Horizon 2020. **In parallel, the share of collaborations between EU-13 participants with each other has been stable since FP6**.

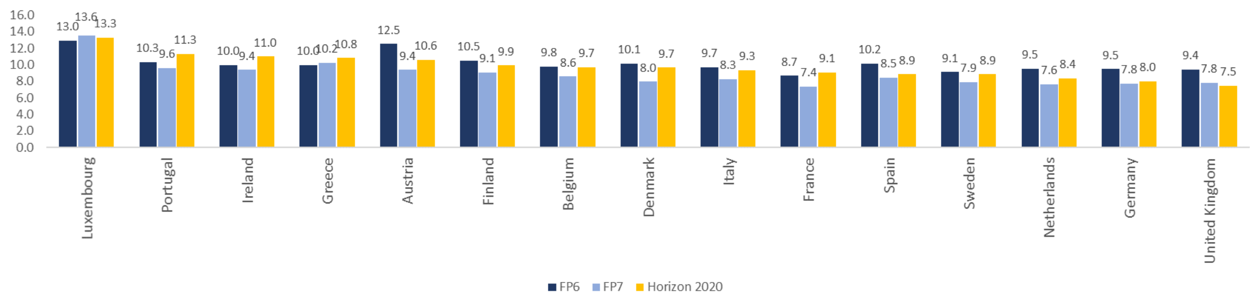
Figure 12 Connections with EU-13 participants as a percentage of all connections of EU-15 participants



Source: Author's calculations based on CORDA data.

The evolution of these collaborations between EU-15 and EU-13 countries is detailed for each EU-15 country in Figure 13[13]. **While there is a clear general decrease in the collaborations with EU-13 participants between FP6 and FP7, almost all EU-15 countries collaborate more often with EU-13 participants in Horizon 2020 compared to FP7.** The only exceptions are Luxembourg and the United Kingdom, which are also respectively the countries with the largest (13.3% in Horizon 2020) and the smallest share of connections (7.5%) with EU-13 participants. Since FP6, this trend has been continuously negative only for the UK and continuously positive only for Greece**.**

Figure 13 Connections with EU-13 countries as a percentage of all connections



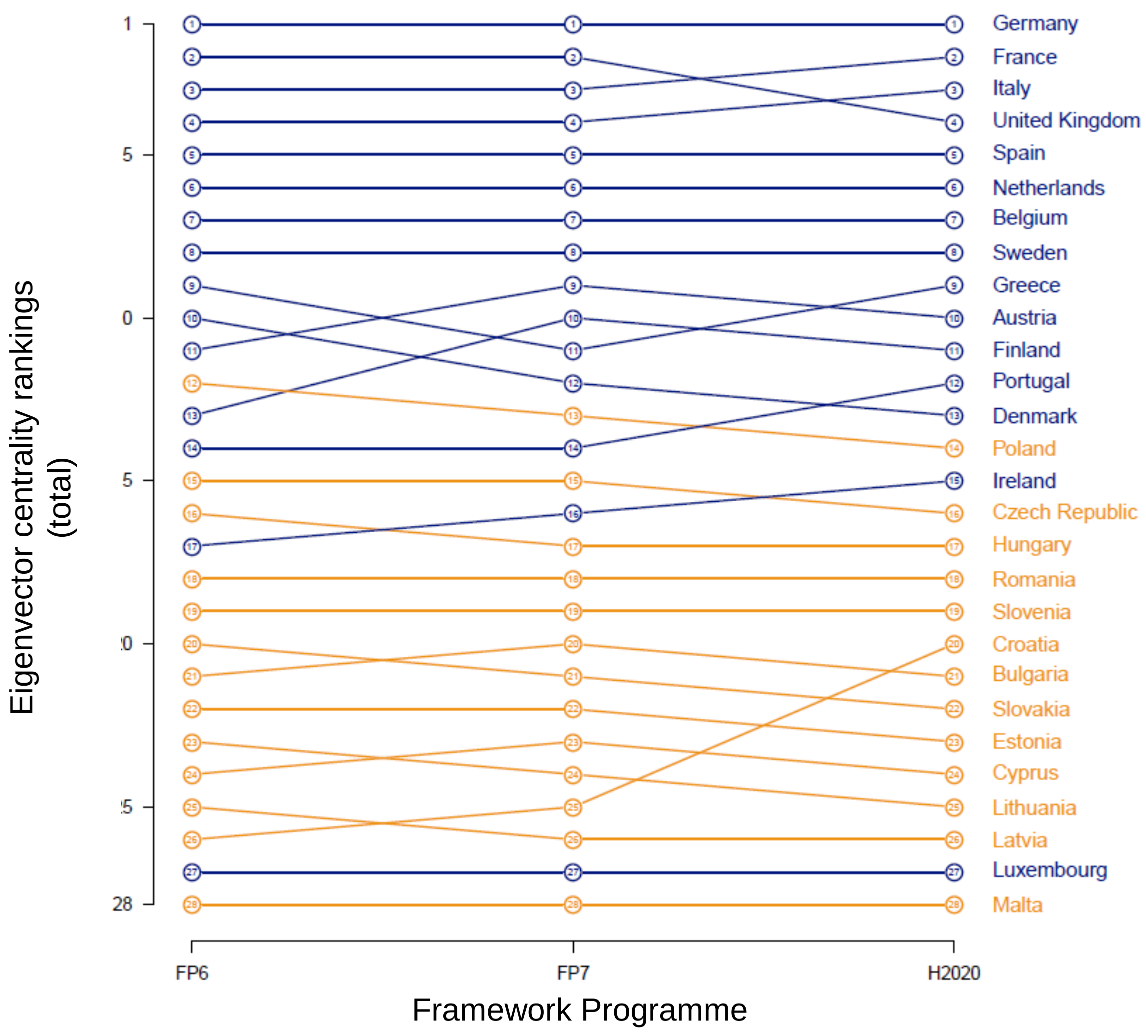
Source: Author's calculations based on CORDA data.

[13] The patterns in Figure 12 and Figure 13 are qualitatively similar. But due to collaborations within country groups, the aggregated values do not numerically correspond to the average of countries.

3.4 How has the position of EU countries evolved over time?

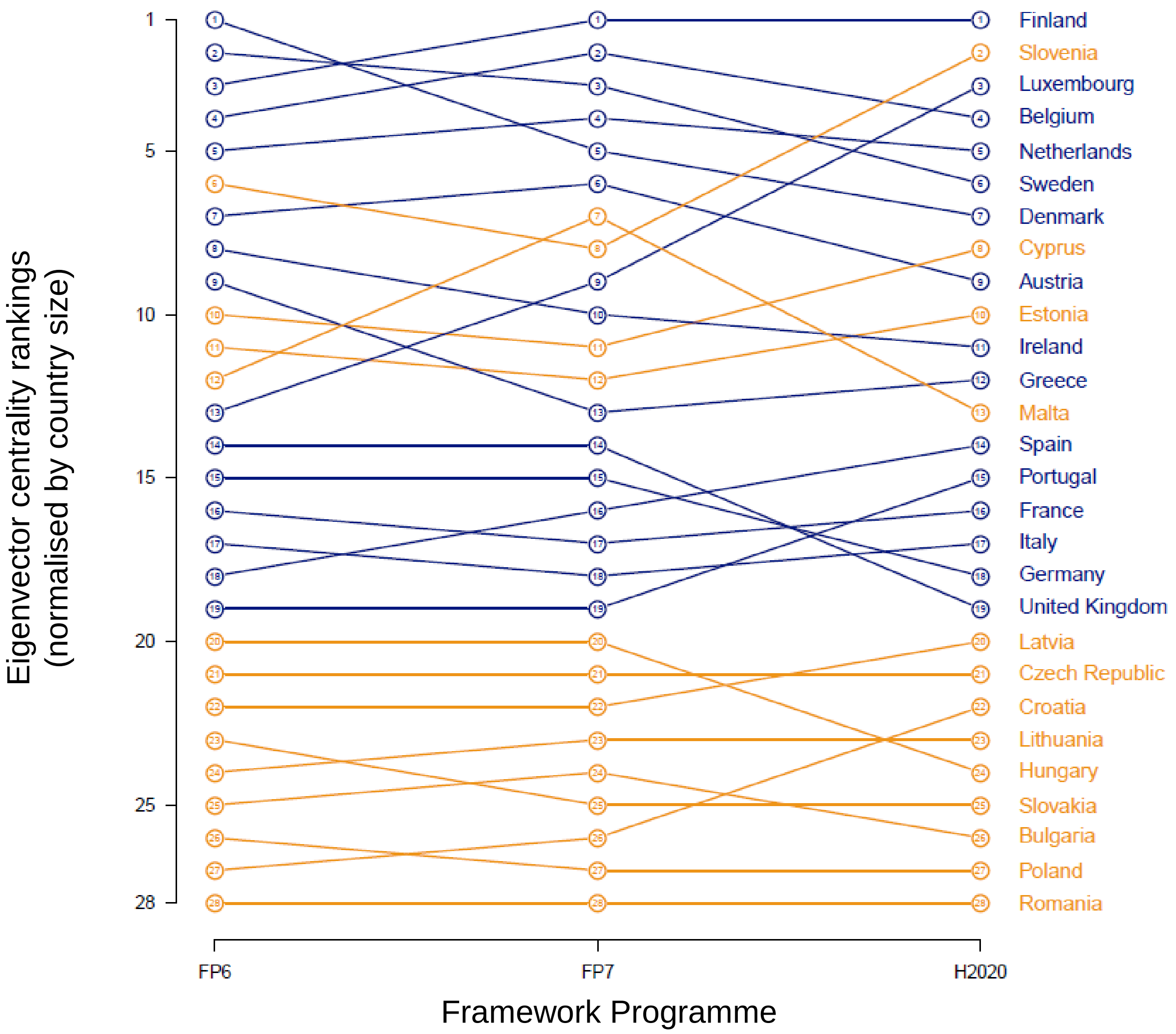
This section presents network indicators computed at the participant level, and averaged or aggregated at the country level. Only EU countries are analysed in this section. Centrality measures for associated countries and third countries are reported in Annex. When examining the position of specific countries in the network, section 2 already suggested that country size is an important determinant in the average number of its participants' connections. This is also reflected in Figure 14, with the evolution of country rankings based on eigenvector centrality measures. **Germany is both the largest participant in the Framework Programme and the most central country in the network. After Germany, France and Italy are the most central countries in Horizon 2020**. While the UK was more central than France and Italy in FP6 and FP7, its central position worsened in Horizon 2020. Greece, Portugal and Ireland have improved their centrality in the network between FP7 and Horizon 2020 according to this ranking. The chart also confirms that participants from EU-15 countries tend to be more central than their EU-13 counterparts: the bottom of the chart is occupied by a majority of EU-13 countries, with only Croatia having significantly improved its position since FP6.

Figure 14 Network positions of participants by EU country



Source: Author's calculations based on CORDA data.

Figure 15 Network positions of participants by EU country normalised by population



Source: Author's calculations based on CORDA data (Framework Programme) and World Bank (country population).

However, these measures are absolute and are significantly influenced by the country size[14]. **Normalisation for size (as measured by population, see Box 5) leads to an overall different picture**. Figure 15 presents the evolution of eigenvector centrality coefficients by country between FP6 and Horizon 2020 when normalising by country population. Different trends can be observed. The most central country, relative to its size, is actually Finland. Some EU-13 countries also appear to be very central in the network for their size: Slovenia is now the second most central country in the network after normalisation for size effect. This was not the case in previous programmes: Slovenia was ranked 5th in FP6 and 8th in FP7 in terms of centrality. This is the most striking increase observed within all EU countries. Luxembourg, the Netherlands, Belgium, Sweden and Denmark are next in terms of size-normalised centrality measure. Among EU-13 countries, Cyprus and Estonia also present strong centrality after normalisation. Hence EU-15 and EU-13 groups are not homogenous groups, with some EU-13 countries being more central, relative to their size, than most EU-15 countries. The position of the UK and Hungary in this ranking dropped significantly between FP7 and

[14] To ensure robustness, other variables describing country size have been tested, such as the national population of researchers (source: Eurostat). This does not affect the key messages from the analysis. However, using population reduces data noise over time and ensures reliability in the evolution of the ranking (see Box 5).

Horizon 2020[15]. Still, several EU-13 countries are consistently found at the bottom of the ranking over the period.

Box 5 Methodology: normalisation for size

Population is used here to normalise eigenvector coefficients by size. Other variables are available for this type of normalisation, in particular R&I-related variables such as number of researchers, but population is particularly relevant for this analysis:

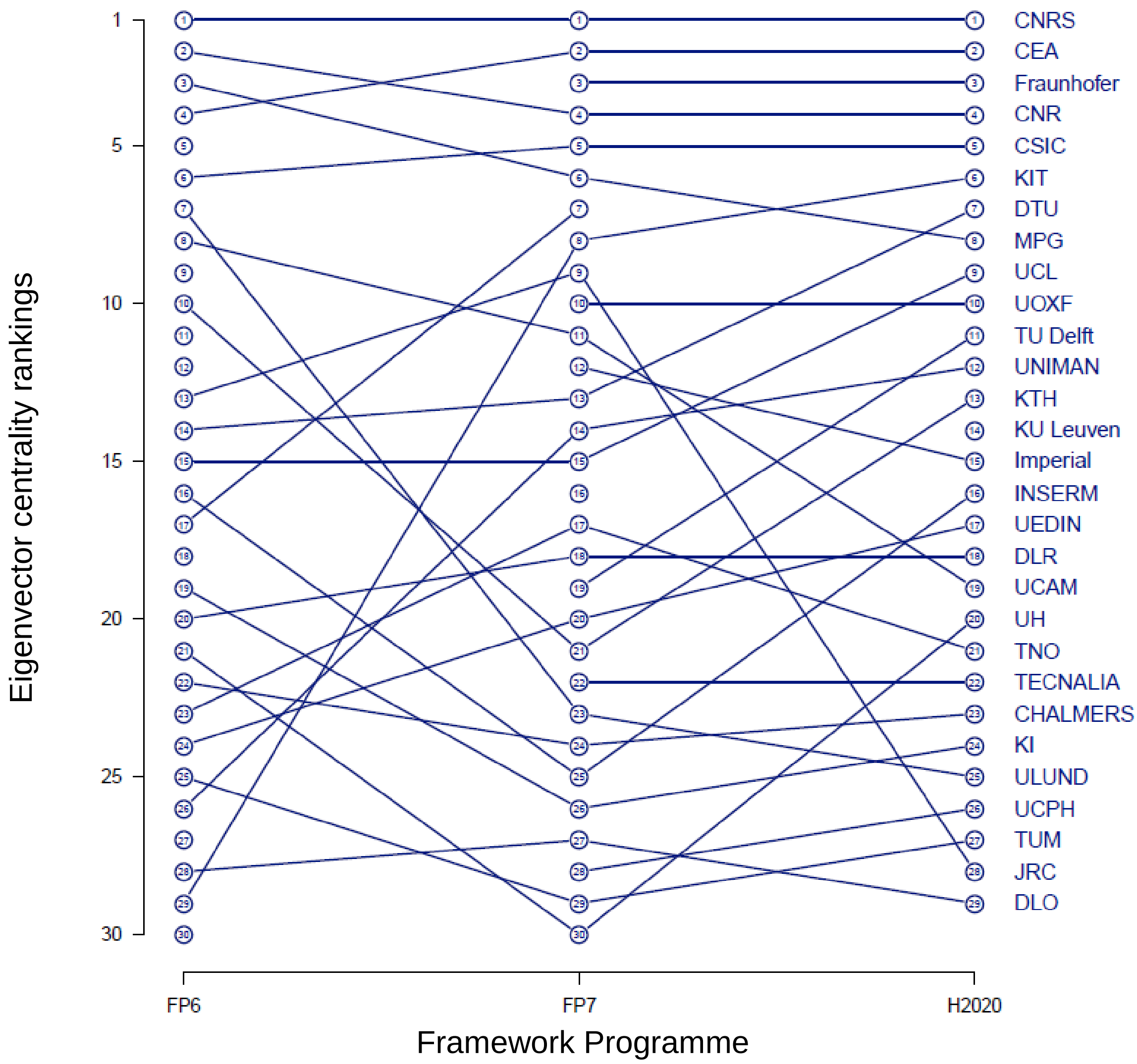
- It is a standard variable to measure country size (i.e. per capita measures) and conceptually neutral with respect to R&I, hence not adding unnecessary noise to the normalised metric. It correlates well with most variables that measure country size. For example, correlation with number of researchers is 92% for the countries covered in this study.
- It is a good candidate for this normalisation as shown by the linear relationship with the number of connections in Figure 2.
- It is more stable in time than other variables directly related to R&I, such as number of researchers. Normalising with these variables adds much noise in the evolution of the centrality rankings: this evolution should be mainly driven by the evolution of the centrality measures rather than by the normalisation factor. This issue particularly affects the evolution for smaller countries. Furthermore, variations in R&I-related variables are expected to impact centrality, but possibly with a delay. Hence, it becomes very difficult to interpret the evolution of the centrality rankings.

Hence, the size-normalised centrality rankings should be interpreted in light of this normalisation approach. An improvement in size-normalised centrality could be for example explained by a strong increase in national R&I capabilities. Another approach to the normalisation of the network is to directly use the number of connections as a normalisation factor. This is the approach used in the relatedness network presented in Section 2.4.

At the participant level, centrality measures show that the top 5 most central participants have been stable over time (Figure 16): CNRS has remained the most central participant since FP6, followed by CEA, Fraunhofer, CNR and CSIC. After these participants, the changes in the ranking of participants have been significant.

[15] The position of Malta also decreased significantly over the same period, but it follows a significant increase in FP7 and the position of small countries is more volatile in the ranking.

Figure 16 Top 30 participants in terms of centrality



Source: Author's calculations based on CORDA data.

4 Conclusion

The overall network of participants in Horizon 2020 shows **that the most central countries in the network are also the largest ones**: Germany, France, the UK, Italy, and Spain. This observation is expected as country size correlates with the number of participations in the Framework Programme and the number of collaborations between participants. **Participants from associated countries and third countries are on average less central than EU participants**, but these country groups are very heterogeneous. For instance, Switzerland and Norway are very important actors in the network.

When examining the evolution over time and normalising for this size effect, results show a different picture. **Some countries punch above their weight: when normalising by country size, the most central country in Horizon 2020 is Finland, followed by Slovenia. Slovenia, Cyprus, Estonia and Malta are as central as EU-15 countries.** Still, other EU-13 countries are found at the bottom of the ranking. Slovenia, Luxembourg, Croatia, Portugal and Cyprus show the most striking increases in terms of size-normalised centrality from FP7 to Horizon 2020, while the UK and Hungary dropped positions.

Between FP6 and FP7, EU-15 participants have been reducing to some extent their collaborations to EU-13 participants. However, **this trend has reverted in Horizon**

2020, as EU-15 countries appear to have opened up to EU-13 participants compared to FP7. Moreover, **the network of participations to the Framework Programmes appears to be very dynamic over time** and tends to be opening to less connected participants. These trends deserve further detailed attention, as well as a more frequent update of observations.

Participants appear to show very specific preferences in their cross-country collaborations. As result, **geographical and cultural proximities between participants seem to play an important role in shaping the structure of the Horizon 2020 collaboration network**.

Overall, while these results show a network that is relatively open, albeit with some persistently peripheral countries. The analysis also presents encouraging trends regarding the openness of the network, in particular between FP7 and Horizon 2020. However, there is still room for improving the connectivity and centrality of several countries, especially countries with lower R&I performance. This calls for continuous emphasis and effort, in particular for these countries, to ensure the openness of the programme's networks to their entities. This could be achieved through support activities such as organising information/networking campaigns, boosting national capacity building, offering further opportunities to entities for accessing successful R&I projects and established networks, or by supporting matchmaking between potential participants informed by analytics and network affinities.

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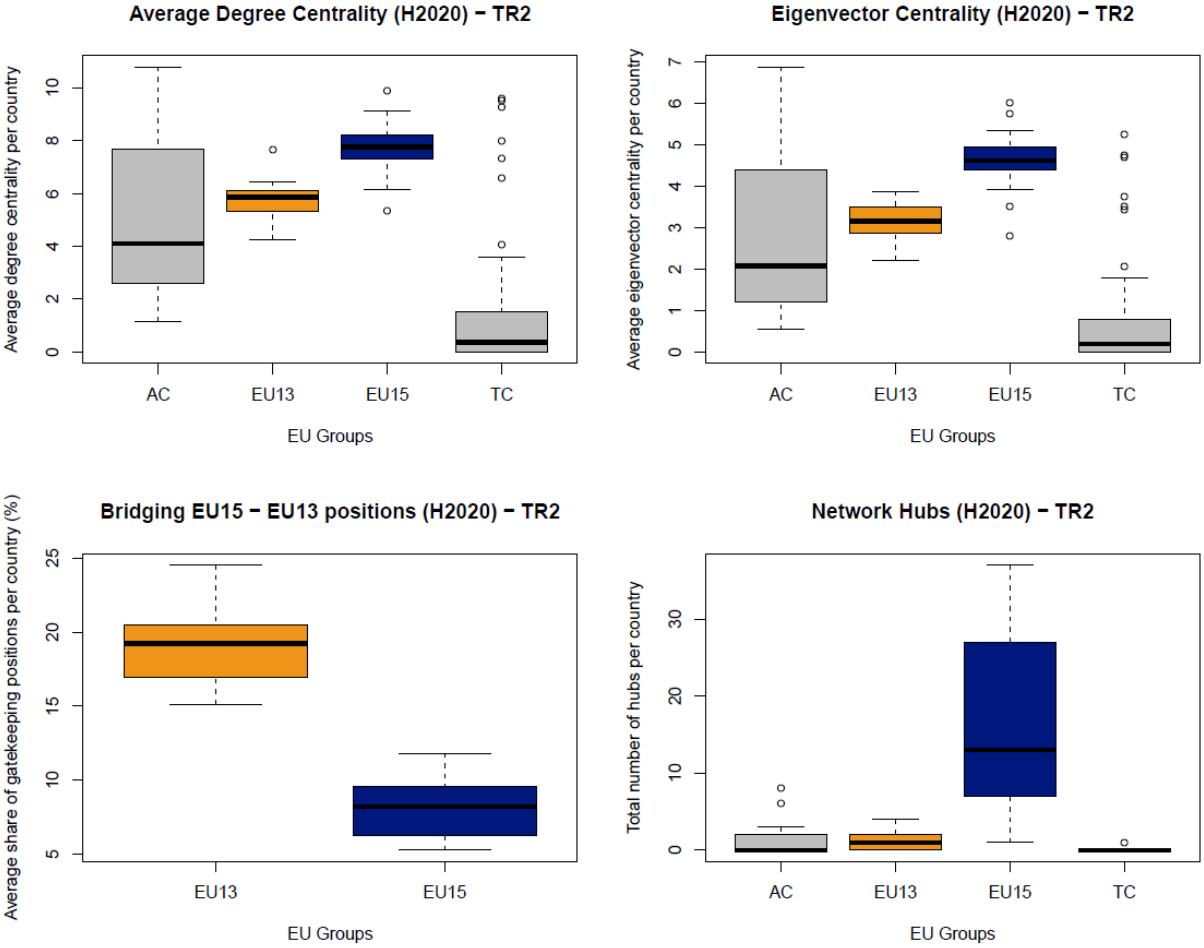
6 Annex

6.1 Alternative threshold (TR2, connections in at least 2 projects)

Figure 17 Centrality with alternative threshold (one-off connections discarded)



6.2 *Horizon 2020 programme parts*

Table 3 Programmes parts in Horizon 2020

Acronym	Programme part
ERC	Future & emerging technologies
MSCA	Marie Skłodowska-Curie actions
RI	Research infrastructures (including e-infrastructure)
LEIT	Leadership in enabling & industrial technologies
ARF	Access to risk finance
Innovation in SMEs	Innovation in SMEs
FTI	Fast Track to Innovation
SC1	Health, demographic change & wellbeing
SC2	Food security, sustainable agriculture and forestry,
SC3	Secure, clean & efficient energy
SC4	Smart, green & integrated transport
SC5	Climate action, environment, resource efficiency & raw materials
SC6	Inclusive, innovative & reflective societies
SC7	Secure societies
SEWP	Spreading excellence & widening participation
SWAFS	Science with and for society
Euratom	Euratom

6.3 Centrality by country and by programme part

Figure 18 Share of country participations by programme part (%)

	ERC	FET	MSCA	RI	LEIT	ARF	Inno. in SMEs	FTI	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SEWP	SWAFS	Euratom
AT	3.58	2.77	3.27	2.14	4.25	0	2.84	1.76	2.35	2.27	3.66	4.26	3.27	4.58	3.34	2.76	5.77	2.48
BE	3.89	3.13	4.17	3.33	4.76	27.5	3.41	3.64	6.44	6.76	4.95	6.85	5.9	6.72	5.3	1.99	5.49	4.25
BG	0.09	0.79	0.43	0.9	0.27	3.57	2.44	5.76	0.23	0.7	1.19	0.32	0.59	0.95	1.31	1.17	1.83	1.41
CY	0.45	0.09	0.38	0.55	0.42	0	0.24	0.52	0.51	0.25	0.68	0.46	0.65	0.79	1	10	1.97	0.38
CZ	1.03	0.55	1.11	2.58	1.46	3.57	0.93	0.52	1.51	1.08	1.46	1.37	1.05	1.32	0.59	2.49	1.97	2.92
DE	15.4	18	15.86	11.6	16.3	5.05	9.81	12.7	13.6	8.98	12.6	16.4	11.1	10	10.2	10.26	9.2	6.19
DK	1.74	1.13	3.07	2	1.62	0	3.69	0.76	3.45	3.33	2.83	1.64	2.7	3.18	0.79	1.25	2.82	0.69
EE	0.18	0.39	0.31	0.8	0.27	0	1.05	0	0.38	0.69	1.24	0.38	0.36	2.43	0.89	1.64	1.37	0.49
EL	1.34	2.98	2.18	3.83	3.82	0.15	4.37	2.44	2.64	3.4	2.93	3.11	3.91	6.54	6.79	1.51	5.03	3.39
ES	7.11	13.1	9.87	8.12	14.4	8.47	14.45	11.9	9.11	11.3	14.5	10	12.5	7.36	11.3	3.5	8.84	12.09
FI	0.85	2.54	1.99	2.86	3.25	4.9	1.01	0.76	2.2	2.08	2.21	1.63	2.85	2.6	2.63	1.72	2.94	3.67
FR	16.4	11.5	10.36	11.3	10.7	11.7	7.14	7.32	10.7	12.5	8.23	12.4	9.53	6.13	9.31	4.8	5.84	21.58
HR	0.49	0.05	0.2	0.75	0.13	0	1.06	0.4	0.74	0.95	0.98	0.47	1.04	0.89	0.37	2.57	1.4	2.53
HU	0.89	0.93	0.83	1.59	0.76	0	1.98	0.2	0.81	1.97	0.79	0.84	1.06	2.1	0.92	2.23	1.61	2.93
IE	1.16	0.85	1.97	1.92	1.83	3.57	1.36	2.04	1.34	2.26	1.46	0.78	1.71	1.75	2.45	0.98	2.85	0.96
IT	10.6	14.8	9.97	10.3	11.2	7.28	11.53	12.1	9.38	12	11.9	11.3	11.4	10.2	12.6	6.39	7.17	9.53
LT	0.04	0.05	0.25	0.36	0.25	0	0.71	0.2	0.5	0.49	0.53	0.51	0.33	1.07	0.2	0.9	1.63	0.77
LU	0.09	0.03	0.28	0.2	0.41	0	0.76	0.32	0.59	0.05	0.3	0.45	0.21	1.09	1.01	1.83	1.16	0
LV	0	0.07	0.19	0.51	0.25	3.71	0.3	0	0.64	0.72	0.73	0.14	0.16	0.84	0.36	2.23	1.21	0.7
MT	0.13	0.03	0.1	0.31	0.06	1.19	0.24	0	0.03	0.11	0.22	0.27	0.25	0.27	0.18	0.8	1.72	0
NL	5.68	4.32	8.18	8.77	6.86	13.4	2.26	11.3	8.92	7.07	5.38	7.07	6.61	5.59	4.84	4	6.44	3.54
PL	0.72	1.03	1.84	3.35	1.42	0	5.53	0.4	1.11	1.93	1.87	1.65	2.15	3.09	3.04	4.16	2.85	4.85
PT	2.1	1.03	2.64	3.35	2.52	0	3.74	1.56	1.99	3.29	3.47	1.61	4.11	2.72	4	10.24	3.69	1.02
RO	0.27	0.1	0.6	1.31	0.74	0	3.85	0.88	0.58	1.47	1.67	1.25	2.02	1.45	2.92	3.26	1.39	3.81
SE	2.32	4.37	3.87	3.86	3.09	0	4.07	2.68	3.57	3.03	4.01	4.42	3.46	3.44	1.7	1.99	2.36	3.27
SI	0.72	0.41	0.64	1.35	0.72	0	1.35	2.76	1.18	1.24	1.35	0.74	1.47	1.16	0.78	4.46	1.95	1.58
SK	0.09	0.09	0.32	0.85	0.38	0	0.73	0.4	0.69	0.46	0.48	0.67	0.5	1.71	0.46	4.06	1.09	0.73
UK	22.6	14.9	15.11	11.2	7.92	5.94	9.16	16.7	14.8	9.59	8.41	8.94	9.09	10	10.8	6.82	8.41	4.23

Source: Author's calculations based on CORDA data.

Figure 19 Share of country participations by programme part (%) with countries organised by decreasing overall centrality (from top to bottom) and programme parts organised by decreasing ubiquity (from left to right)

	SWAFS	RI	SC6	Inno. in SMEs	SC3	SC2	SEWP	SC5	SC7	SC1	Euratom	SC4	LEIT	ARF	FTI	FET	MSCA	ERC
DE	9.2	11.6	10	9.81	12.6	8.98	10.26	11.1	10.2	13.6	6.19	16.4	16.3	5.05	12.7	18	15.86	15.4
ES	8.84	8.12	7.36	14.45	14.5	11.3	3.5	12.5	11.3	9.11	12.09	10	14.4	8.47	11.9	13.1	9.87	7.11
IT	7.17	10.3	10.2	11.53	11.9	12	6.39	11.4	12.6	9.38	9.53	11.3	11.2	7.28	12.1	14.8	9.97	10.6
FR	5.84	11.3	6.13	7.14	8.23	12.5	4.8	9.53	9.31	10.7	21.58	12.4	10.7	11.7	7.32	11.5	10.36	16.4
UK	8.41	11.2	10	9.16	8.41	9.59	6.82	9.09	10.8	14.8	4.23	8.94	7.92	5.94	16.7	14.9	15.11	22.6
NL	6.44	8.77	5.59	2.26	5.38	7.07	4	6.61	4.84	8.92	3.54	7.07	6.86	13.4	11.3	4.32	8.18	5.68
BE	5.49	3.33	6.72	3.41	4.95	6.76	1.99	5.9	5.3	6.44	4.25	6.85	4.76	27.5	3.64	3.13	4.17	3.89
SE	2.36	3.86	3.44	4.07	4.01	3.03	1.99	3.46	1.7	3.57	3.27	4.42	3.09	0	2.68	4.37	3.87	2.32
EL	5.03	3.83	6.54	4.37	2.93	3.4	1.51	3.91	6.79	2.64	3.39	3.11	3.82	0.15	2.44	2.98	2.18	1.34
AT	5.77	2.14	4.58	2.84	3.66	2.27	2.76	3.27	3.34	2.35	2.48	4.26	4.25	0	1.76	2.77	3.27	3.58
PT	3.69	3.35	2.72	3.74	3.47	3.29	10.24	4.11	4	1.99	1.02	1.61	2.52	0	1.56	1.03	2.64	2.1
FI	2.94	2.86	2.6	1.01	2.21	2.08	1.72	2.85	2.63	2.2	3.67	1.63	3.25	4.9	0.76	2.54	1.99	0.85
DK	2.82	2	3.18	3.69	2.83	3.33	1.25	2.7	0.79	3.45	0.69	1.64	1.62	0	0.76	1.13	3.07	1.74
PL	2.85	3.35	3.09	5.53	1.87	1.93	4.16	2.15	3.04	1.11	4.85	1.65	1.42	0	0.4	1.03	1.84	0.72
IE	2.85	1.92	1.75	1.36	1.46	2.26	0.98	1.71	2.45	1.34	0.96	0.78	1.83	3.57	2.04	0.85	1.97	1.16
CZ	1.97	2.58	1.32	0.93	1.46	1.08	2.49	1.05	0.59	1.51	2.92	1.37	1.46	3.57	0.52	0.55	1.11	1.03
RO	1.39	1.31	1.45	3.85	1.67	1.47	3.26	2.02	2.92	0.58	3.81	1.25	0.74	0	0.88	0.1	0.6	0.27
HU	1.61	1.59	2.1	1.98	0.79	1.97	2.23	1.06	0.92	0.81	2.93	0.84	0.76	0	0.2	0.93	0.83	0.89
SI	1.95	1.35	1.16	1.35	1.35	1.24	4.46	1.47	0.78	1.18	1.58	0.74	0.72	0	2.76	0.41	0.64	0.72
BG	1.83	0.9	0.95	2.44	1.19	0.7	1.17	0.59	1.31	0.23	1.41	0.32	0.27	3.57	5.76	0.79	0.43	0.09
HR	1.4	0.75	0.89	1.06	0.98	0.95	2.57	1.04	0.37	0.74	2.53	0.47	0.13	0	0.4	0.05	0.2	0.49
EE	1.37	0.8	2.43	1.05	1.24	0.69	1.64	0.36	0.89	0.38	0.49	0.38	0.27	0	0	0.39	0.31	0.18
SK	1.09	0.85	1.71	0.73	0.48	0.46	4.06	0.5	0.46	0.69	0.73	0.67	0.38	0	0.4	0.09	0.32	0.09
CY	1.97	0.55	0.79	0.24	0.68	0.25	10	0.65	1	0.51	0.38	0.46	0.42	0	0.52	0.09	0.38	0.45
LT	1.63	0.36	1.07	0.71	0.53	0.49	0.9	0.33	0.2	0.5	0.77	0.51	0.25	0	0.2	0.05	0.25	0.04
LV	1.21	0.51	0.84	0.3	0.73	0.72	2.23	0.16	0.36	0.64	0.7	0.14	0.25	3.71	0	0.07	0.19	0
LU	1.16	0.2	1.09	0.76	0.3	0.05	1.83	0.21	1.01	0.59	0	0.45	0.41	0	0.32	0.03	0.28	0.09
MT	1.72	0.31	0.27	0.24	0.22	0.11	0.8	0.25	0.18	0.03	0	0.27	0.06	1.19	0	0.03	0.1	0.13

Source: Author's calculations based on CORDA data.

6.4 Centrality rankings for EU countries

Figure 20 Centrality rankings for EU countries

Country	Eigenvector centrality (x1000)			Eigenvector centrality ranking			Eigenvector centrality normalised by size			Ranking after normalisation		
	FP6	FP7	Horizon 2020	FP6	FP7	Horizon 2020	FP6	FP7	Horizon 2020	FP6	FP7	Horizon 2020
Austria	1956.6	2811.4	3084.2	11	9	10	238.7	335.7	355.2	7	6	9
Belgium	3391.9	4607.7	4641.6	7	7	7	324.4	422.2	410.9	4	2	4
Bulgaria	378.1	483.9	509.0	21	20	21	49.2	65.4	71.2	25	24	26
Croatia	129.8	262.2	524.3	26	25	20	29.2	60.1	125.3	27	26	22
Cyprus	202.3	292.6	418.0	24	23	24	198.4	264.0	358.6	10	11	8
Czech Republic	1174.9	1252.6	1391.7	15	15	16	115.1	119.9	131.8	21	21	21
Denmark	2037.0	2167.7	2064.9	10	12	13	376.3	391.1	361.9	1	5	7
Estonia	268.3	337.0	444.2	22	22	23	197.5	253.3	337.7	11	12	10
Finland	1734.9	2681.9	2677.0	13	10	11	331.2	500.0	487.9	3	1	1
France	9100.2	10914.0	12897.3	3	3	2	144.6	167.9	193.3	16	17	16
Germany	12843.0	15873.5	14554.3	1	1	1	155.7	195.1	177.6	15	15	18
Greece	2296.2	2625.3	3123.7	9	11	9	209.3	237.2	288.9	9	13	12
Hungary	1162.4	1208.6	1002.9	16	17	17	115.1	121.0	102.1	20	20	24
Ireland	893.0	1249.7	1508.2	17	16	15	216.5	275.2	318.7	8	10	11
Italy	7523.7	9791.4	11057.9	4	4	3	130.2	165.2	182.2	17	18	17
Latvia	175.9	204.0	305.2	25	26	26	78.1	97.0	155.1	22	22	20
Lithuania	222.5	266.9	344.8	23	24	25	66.5	86.3	119.6	24	23	23
Luxembourg	78.5	149.7	248.7	27	27	27	170.0	293.9	431.1	13	9	3
Malta	77.4	137.4	116.8	28	28	28	192.3	331.1	259.6	12	7	13
Netherlands	4712.2	6787.2	6770.5	6	6	6	289.2	408.8	398.5	5	4	5
Poland	1846.1	1673.7	1850.5	12	13	14	48.4	43.9	48.7	26	27	27
Portugal	1280.0	1667.9	2212.2	14	14	12	122.0	158.3	213.9	19	19	15
Romania	529.0	827.7	925.3	18	18	18	24.7	40.7	46.8	28	28	28
Slovakia	379.6	347.1	459.2	20	21	22	70.6	64.4	84.6	23	25	25
Slovenia	489.0	662.1	891.7	19	19	19	244.5	324.2	432.0	6	8	2
Spain	5318.2	8393.9	10921.5	5	5	5	122.8	181.2	234.9	18	16	14
Sweden	3351.9	3915.7	3778.0	8	8	8	371.8	417.8	382.7	2	3	6
United Kingdom	10139.5	12414.3	11004.3	2	2	4	168.4	197.8	168.4	14	14	19

Source: Author's calculations based on CORDA data.

6.5 Eigenvector centrality measures for all countries

Note: AC = associated countries, TC = third countries (Horizon 2020 situation).

Figure 21 Centrality ranking for all countries (Horizon 2020)

Country	Group	FP6	*rank*	FP7	*rank*	Horizon 2020	*rank*
Germany	EU15	12843.0	*1*	15873.5	*1*	14554.3	*1*
France	EU15	9100.2	*3*	10914.0	*3*	12897.3	*2*
Italy	EU15	7523.7	*4*	9791.4	*4*	11057.9	*3*
United Kingdom	EU15	10139.5	*2*	12414.3	*2*	11004.3	*4*
Spain	EU15	5318.2	*5*	8393.9	*5*	10921.5	*5*
Netherlands	EU15	4712.2	*6*	6787.2	*6*	6770.5	*6*
Belgium	EU15	3391.9	*7*	4607.7	*7*	4641.6	*7*
Sweden	EU15	3351.9	*8*	3915.7	*8*	3778.0	*8*
Switzerland	AC	2919.2	*9*	3671.0	*9*	3412.1	*9*
Greece	EU15	2296.2	*10*	2625.3	*12*	3123.7	*10*
Austria	EU15	1956.6	*12*	2811.4	*10*	3084.2	*11*
Finland	EU15	1734.9	*14*	2681.9	*11*	2677.0	*12*
Portugal	EU15	1280.0	*16*	1667.9	*16*	2212.2	*13*
Norway	AC	1385.9	*15*	1890.7	*14*	2067.4	*14*
Denmark	EU15	2037.0	*11*	2167.7	*13*	2064.9	*15*
Poland	EU13	1846.1	*13*	1673.7	*15*	1850.5	*16*
Ireland	EU15	893.0	*19*	1249.7	*18*	1508.2	*17*
Czech Republic	EU13	1174.9	*17*	1252.6	*17*	1391.7	*18*
Hungary	EU13	1162.4	*18*	1208.6	*19*	1002.9	*19*
Israel	AC	867.2	*20*	1084.4	*20*	960.2	*20*
Romania	EU13	529.0	*22*	827.7	*21*	925.3	*21*
Slovenia	EU13	489.0	*23*	662.1	*22*	891.7	*22*
United States	TC	270.5	*28*	541.3	*24*	742.6	*23*
Turkey	AC	416.0	*24*	644.9	*23*	546.0	*24*
Croatia	EU13	129.8	*35*	262.2	*32*	524.3	*25*
Bulgaria	EU13	378.1	*26*	483.9	*26*	509.0	*26*
Slovakia	EU13	379.6	*25*	347.1	*27*	459.2	*27*
Estonia	EU13	268.3	*29*	337.0	*28*	444.2	*28*
Cyprus	EU13	202.3	*31*	292.6	*29*	418.0	*29*
Lithuania	EU13	222.5	*30*	266.9	*31*	344.8	*30*
China	TC	291.2	*27*	270.4	*30*	329.8	*31*
Latvia	EU13	175.9	*32*	204.0	*36*	305.2	*32*
Serbia	AC			185.8	*37*	250.2	*33*
Luxembourg	EU15	78.5	*44*	149.7	*42*	248.7	*34*
Ukraine	AC	127.6	*36*	169.0	*39*	208.7	*35*
Iceland	AC	115.8	*38*	226.0	*34*	204.8	*36*
Canada	TC	124.8	*37*	225.8	*35*	193.7	*37*
Australia	TC	151.2	*34*	231.2	*33*	191.3	*38*
Russian Federation	TC	663.6	*21*	487.7	*25*	185.5	*39*
Brazil	TC	113.0	*39*	145.4	*43*	178.4	*40*
South Africa	TC	171.7	*33*	170.0	*38*	177.8	*41*

Country	Group	FP6	*rank*	FP7	*rank*	Horizon 2020	*rank*
Japan	TC	23.7	*57*	167.2	*40*	136.6	*42*
Malta	EU13	77.4	*45*	137.4	*44*	116.8	*43*
Korea (Republic of)	TC	26.6	*54*	85.3	*47*	91.0	*44*
Argentina	TC	88.4	*43*	65.8	*48*	87.6	*45*
Taiwan (Province of China)	TC	13.2	*71*	40.8	*55*	71.0	*46*
Macedonia (the Former Yugoslav Republic of)	TC	18.9	*64*	47.2	*52*	62.7	*47*
Belarus	TC	37.3	*51*	38.3	*56*	55.9	*48*
Mexico	TC	44.9	*49*	62.2	*49*	54.0	*49*
Tunisia	AC	100.4	*41*	55.3	*50*	52.4	*50*
Morocco	TC	101.3	*40*	94.0	*45*	51.3	*51*
Kenya	TC	32.3	*52*	44.3	*53*	50.2	*52*
Chile	TC	69.9	*46*	50.6	*51*	50.0	*53*
Moldova (Republic of)	TC	3.6	*98*	18.0	*78*	40.3	*54*
Colombia	TC	7.5	*84*	25.2	*62*	37.2	*55*
Malaysia	TC	6.2	*87*	24.9	*63*	37.0	*56*
New Zealand	TC	16.9	*66*	42.4	*54*	35.5	*57*
India	TC	97.3	*42*	156.4	*41*	33.8	*58*
Thailand	TC	13.8	*68*	27.0	*61*	32.6	*59*
Egypt	TC	66.0	*47*	85.6	*46*	30.8	*60*
Senegal	TC	46.6	*48*	29.0	*59*	29.3	*61*
Indonesia	TC	14.8	*67*	20.9	*72*	27.0	*62*
Viet Nam	TC	10.7	*77*	21.7	*71*	26.8	*63*
Hong Kong	TC	11.1	*73*	11.9	*88*	25.3	*64*
Faroe Islands	AC	2.7	*106*	15.0	*83*	24.2	*65*
Albania	AC	10.8	*76*	23.4	*65*	23.2	*66*
Bosnia and Herzegovina	AC	10.9	*75*	18.9	*76*	21.6	*67*
Philippines	TC	11.0	*74*	20.0	*73*	21.6	*68*
Uganda	TC	13.6	*69*	22.9	*67*	21.0	*69*
Uruguay	TC	20.2	*62*	19.0	*75*	21.0	*70*
Georgia	AC	19.1	*63*	37.8	*57*	18.2	*71*
Tanzania (United Republic of)	TC	12.0	*72*	22.7	*68*	17.0	*72*
Greenland	TC	1.1	*114*	8.7	*94*	14.0	*73*
Lebanon	TC	25.3	*55*	22.2	*70*	13.9	*74*
Ghana	TC	17.7	*65*	22.2	*69*	13.6	*75*
Montenegro	AC			27.4	*60*	13.3	*76*
Costa Rica	TC	6.1	*88*	8.4	*95*	13.2	*77*
Iran (Islamic Republic of)	TC	0.7	*120*	3.3	*117*	13.0	*78*
Cuba	TC	0.8	*117*	3.6	*115*	12.8	*79*
New Caledonia	TC	0.0	*129*	0.4	*133*	12.6	*80*
Ethiopia	TC	8.5	*81*	12.2	*87*	12.4	*81*
Mozambique	TC	5.7	*90*	8.7	*93*	12.0	*82*
Armenia	AC	2.9	*104*	19.3	*74*	11.1	*83*
Ecuador	TC	13.6	*70*	7.4	*98*	10.9	*84*
Burkina Faso	TC	23.2	*58*	15.8	*82*	10.8	*85*
Jordan	TC	21.6	*60*	18.7	*77*	10.1	*86*

Country	Group	FP6	rank	FP7	rank	Horizon 2020	rank
Nigeria	TC	7.7	*83*	17.9	*79*	9.7	*87*
Singapore	TC	30.6	*53*	30.5	*58*	9.4	*88*
Algeria	TC	44.3	*50*	23.4	*64*	9.1	*89*
Peru	TC	10.0	*79*	16.6	*80*	7.0	*90*
Madagascar	TC	0.4	*123*	4.7	*108*	6.8	*91*
Cape Verde	TC	3.2	*100*	9.8	*89*	6.6	*92*
Côte d'Ivoire	TC	2.1	*109*	2.0	*122*	6.2	*93*
Cambodia	TC	3.0	*102*	3.2	*119*	5.9	*94*
French Polynesia	TC	0.0	*129*	1.1	*129*	5.8	*95*
Namibia	TC	4.0	*95*	5.1	*104*	5.6	*96*
Kazakhstan	TC	3.8	*97*	15.9	*81*	5.6	*97*
Cameroon	TC	7.1	*86*	22.9	*66*	5.4	*98*
Bolivia (Plurinational State of)	TC	10.3	*78*	7.5	*97*	5.1	*99*
Jamaica	TC	0.5	*121*	4.4	*111*	5.0	*100*
Rwanda	TC	1.0	*116*	4.4	*110*	5.0	*101*
Pakistan	TC	3.9	*96*	3.5	*116*	5.0	*102*
Palestine (State of)	TC	20.7	*61*	12.3	*86*	4.9	*103*
Mali	TC	22.9	*59*	9.4	*92*	4.2	*104*
Malawi	TC	2.0	*110*	7.7	*96*	3.9	*105*
Benin	TC	8.6	*80*	4.7	*107*	3.7	*106*
Venezuela (Bolivarian Republic of)	TC	4.1	*94*	5.1	*105*	3.6	*107*
Azerbaijan	TC	0.7	*118*	12.8	*85*	3.4	*108*
Saudi Arabia	TC	0.2	*125*	6.7	*100*	3.3	*109*
Sri Lanka	TC	1.1	*115*	5.7	*101*	3.1	*110*
Gibraltar	TC			1.9	*125*	3.0	*111*
Iraq	TC	0.4	*124*			3.0	*112*
Zambia	TC	4.4	*93*	4.3	*112*	2.7	*113*
Liberia	TC					2.6	*114*
Nepal	TC	3.0	*103*	1.3	*127*	2.6	*115*
Angola	TC	0.0	*128*	1.2	*128*	2.2	*116*
Bangladesh	TC	3.5	*99*	13.4	*84*	2.1	*117*
Kyrgyzstan	TC	2.1	*108*	9.7	*90*	1.9	*118*
Togo	TC	0.5	*122*	2.0	*121*	1.9	*119*
Qatar	TC			0.5	*131*	1.7	*120*
Guatemala	TC	4.4	*92*	2.3	*120*	1.7	*121*
Gabon	TC	8.3	*82*	5.3	*103*	1.6	*122*
Niger	TC	23.9	*56*	5.6	*102*	1.6	*123*
Afghanistan	TC	7.2	*85*	0.2	*136*	1.6	*124*
Mauritius	TC			1.9	*123*	1.5	*125*
Nicaragua	TC	2.8	*105*	1.9	*124*	1.4	*126*
Botswana	TC	5.5	*91*	3.3	*118*	1.3	*127*
Liechtenstein	TC	3.0	*101*	9.7	*91*	1.0	*128*
Mauritania	TC	1.2	*112*	0.4	*134*	0.8	*129*
Seychelles	TC	2.7	*106*	0.9	*130*	0.8	*129*
Burundi	TC			0.0	*139*	0.8	*131*

Country	Group	FP6	*rank*	FP7	*rank*	Horizon 2020	*rank*
Virgin Islands (British)	TC			0.2	*135*	0.7	*132*
United Arab Emirates	TC	0.2	*126*	5.0	*106*	0.6	*133*
Myanmar	TC			0.0	*140*	0.6	*134*
Uzbekistan	TC	5.7	*89*	7.1	*99*	0.5	*135*
Anguilla	TC					0.5	*136*
Tajikistan	TC	1.1	*113*	4.3	*113*	0.4	*137*
Grenada	TC					0.3	*138*
Yemen	TC			0.5	*131*	0.3	*139*
Mongolia	TC					0.3	*140*
Libya	TC			3.7	*114*	0.3	*141*
Sao Tome and Principe	TC					0.2	*142*
Sierra Leone	TC					0.1	*143*
Lao People's Democratic Republic	TC	1.9	*111*	4.6	*109*	0.1	*144*
Paraguay	TC	0.7	*119*			0.1	*145*
Jersey	TC					0.1	*146*
Turkmenistan	TC	0.2	*127*	1.9	*126*	0.0	*147*
Lesotho	TC			0.0	*138*	0.0	*148*
Swaziland	TC			0.1	*137*	0.0	*148*

Source: Author's calculations based on CORDA data.

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This study explores cross-country collaborations between participants to the 6th Framework Programme, the 7th Framework Programme and Horizon 2020. It provides evidence related the dynamic evolution of the network of participants to the Framework Programmes. In particular, the analysis highlights how the situation of entities of country groups (EU-15, EU-13, associated countries and third countries) has changed over the last decade.

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