The Structure of EU Funded R&D Collaboration Networks in the Area of Information Society Technologies

Aimilia Protogerou, Yannis Caloghirou and Evangelic Siokas

Laboratory of Industrial and Energy Economics
National Technical University of Athens, Zografou Campus, Athens, Greece.

Abstract

In the last two decades collaborative networks are increasingly responsible for new developments in research and knowledge creation. This paper examines the structure of the networks formed under the 4th, 5th and 6th EU Framework Programmes in the area of Information Society Technologies. Our findings suggest that the networks examined display characteristics typical for complex networks such as small-world property and scale free-distributions. Moreover, several findings indicate that they are structured around a core of organizations, mainly universities and research centres which have assumed a very influential role over time.

Introduction

In a dynamic environment characterized by rapid change and complex innovations such as a knowledge-based economy, networks emerge as a new form of organization within knowledge production. Network structures associate diverse streams of knowledge embedded in different organizations in order to facilitate rapid exchange and decision making. Under this perspective networks can be understood as mechanisms enabling and facilitating knowledge diffusion through collaboration and the interactive relationship becomes not only an important co-ordination device, but

---

1 This paper is part of a research project which is co-funded by the European Social Fund (75%) and National resources (25%) – Operational Programme for Education and Initial Vocational Training and in particular the Pythagoras II Programme
also a crucial factor for the enhancement of technological progress and development (Küppers and Pyka, 2002).

During the past couple of decades, the promotion of collaborative research and development (R&D) has become one of the top priorities of the science and technology policy in industrialized countries (see Caloghirou et al., 2002). In Europe, principle examples are the European Framework Programmes (FPs) on Research and Technological Development which have been basic pillars of European scientific and technological development, integration and cohesion during the last twenty years. They have supported all kinds of R&D in high technology sectors; have fostered the participation of European organizations in cross-border partnerships and have created a sense of European “togetherness” in science and technology (Caloghirou et al., 2004).

Technology collaboration networks are the result of R&D partnerships, which are defined as cooperative arrangements, engaging companies, universities and/or government agencies and laboratories, in various combinations to pool resources in pursuit of a shared R&D perspective (Hagedoorn et al., 2000). The present paper focuses on a special form of collaborative R&D: subsidized research joint ventures (RJVs) that have been established through project-based ventures in the European Research Area. The research partnerships that will be examined are contractual agreements among independent entities, which may include firms, universities, research institutes and other organizations. More specifically, our attention is centred on RJVs established during the period 1994-2006 in the area of Information Society Technologies (IST). The IST theme has a central place in the European information and communication technologies (ICTs) landscape as it is meant to form a coherent whole with other European and national research, development and innovation initiatives related to ICT and the Information Society at large.

Although the concepts of “knowledge” and “innovation networks” have been receiving a lot of theoretical attention, quantitative research on this topic seems to be still in its infancy. In contrast with the abundance of case studies, there are only a few empirical studies which attempt to detect social networks on a large scale and explore their role in spreading knowledge across and within regions (Breschi and Lissoni, 2004; Borgatti and Foster, 2003). The main obstacles in the way of these efforts are both of conceptual and empirical nature. First, the identification of useful data
sources, in other words data which give birth to the creation of networks promoting and facilitating knowledge exchange and diffusion. Second, the empirical analysis requires the collection of a large amount of relational data which is a costly and time-consuming process (Breschi and Lissoni, 2004).

Our empirical analysis will be based on an extensive database which includes detailed information on collaborative cross-national research projects funded by the 4th, 5th and 6th FPs under the IST thematic priority. These research projects are analyzed under a network perspective. In this light each research collaboration is seen in the broader context of all its present and past collaborations and each actor that participates in a network does not only gain access to the resources of its immediate partners, but also to a certain extend to those with whom its partners collaborate. Social network analysis is employed in order to describe the topology, and the dynamics of the three networks that were developed in the context of each FP. Appraisal of network topology provides a detailed view of the structural properties of the RJV networks and indicates the determinant factors of their architecture and how they have been evolving over time. Analysis of clustering and “small worlds” allows for drawing conclusions about the efficiency of the specific R&D collaboration networks as mechanisms of knowledge diffusion (Verspagen, 2006; Cowan 2005). Furthermore, analysis of organizations’ positioning in each network space allows for a discussion on their specific role in the network. Last but not least, understanding how these network are formed and how they have evolved over time may provide a useful benchmark tool for the current and future EU Programmes aimed at shaping European Research Area.

**Research joint ventures and networks**

Most innovations involve a multitude of organizations. This is especially the case for the most knowledge-intensive and complex technologies such as computers, semiconductors, telecommunications equipment or biotechnology.

The growth in the number of collaborative innovation agreements, such as strategic technology alliances or research joint ventures has led to the emergence of complex technology networks (Borgatti and Foster, 2003; Verspagen and Duysters, 2004). The growing significance of these networks introduced a shift in the literature away from the dyadic relations between firms focusing on inter-organizational network structures.
which affect learning and innovation (Kogut, 2000; Powell et al., 1996). When analysis is focused on a set or a group of alliances the entire set of collaborative activities becomes the network. This implies that both direct and indirect linkages are being studied. Indirect links result when partners have access not only to an immediate partner but also to those partners with whom their immediate partners collaborate.

Research partnerships can be defined as innovation-based relationships that involve, at least to a certain extent, a major effort in research and development (Hagerdoorn et al., 2000). A special case of R&D partnerships are subsidized Research Join Ventures (RJVs) that have been established through project-based ventures in the European Research Area. These research partnerships are contractual agreements among independent entities such as firms, universities, research institutes and other organizations generally aimed at undertaking joint work towards specific goals in a pre-defined area. The work undertaken in the context of an RJV is usually of pre-competitive nature, which practically means that the fact that two or more organizations are sharing and developing new technological knowledge does not necessarily lead to joint product development.

The networks formed in the context of Framework Programmes are the result of self-organized partnering by participating entities under the thematic priorities and funding rules imposed by EU. They can be characterized as exploration networks since they are mainly focused on pre-competitive research. In this way, they provide information on a different stage of the innovation process compared to networks formed by alliance data, patents, patent citations or scientific publications and thus may offer useful complementary evidence. Moreover, they involve a wider set of actors, i.e. Universities, research centers and government agencies, compared to other R&D collaboration forms. In sum, we could argue that RJV networks can provide valuable information on the organizational fabric and social infrastructure of European science and technology. However, little is known about the kind of network structures formed through these initiatives or their evolution over time. In addition, it is likely that network structures influence network functions such as knowledge creation, knowledge diffusion and the collaboration of particular partners through time. Therefore, better understanding of the formation and evolution of RJV networks
would be of great importance for designing, implementing and assessing new policy measures aiming at strengthening the European Research Area.

**EU Framework Programmes**

The current profile of EU science and technology policy began to emerge in the early 1980s. During this period concerns began to be raised regarding the deteriorating innovation potential and market share of European firms in global markets, and especially the IT industry, in comparison to their American and Japanese counterparts. These concerns led to the launch of a major information technology programme in 1982 (ESPRIT). This research programme provided financial support for pre-competitive, generic research which was jointly conducted by firms, universities and research institutes. ESPRIT I served subsequently as a model for the creation of a more general, “umbrella type” programme, which was referred to as the First Framework Programme on R&D and included research in various technology areas, such as telecommunications, industrial technologies, medicine and biotechnologies (Caloghirou et al. 2004).

Since 1984, six Framework Programmes have been concluded and the seventh (2007-2013) has been recently launched, encouraging technological collaboration among organizations originating from all member countries of the European Union.

The first three FPs represented programmes that were supply or technology oriented. Their main aim was to promote the competitiveness of European industries by raising their technological level through the establishment of R&D collaborations among firms and public research institutes. Joint research activities were supposed to assist firms to advance their technological know-how and solve generic research problems that had wide applications across many economic sectors. This model was originally taken from Japan where it was considered to have been successful and in the very beginning the participating firms were major competitors (Peterson and Sharp, 1998).

However, in the early nineties a new theoretical conceptualization of the innovation process gained importance and began to influence the EU policy advisory circles. Under this new perception, innovation is understood as a complex, interactive knowledge-sharing process that involves a wide set of heterogeneous actors. This new systemic model provides novel directions for the STI policy and in particular collaborative R&D. These comprise, for instance, the necessity to foster interactive
learning as a key mechanism for knowledge generation, to enhance the linkages among different actors involved in innovation processes that rely on the convergence of different knowledge bases, to promote the rapid and wide diffusion of new knowledge and to build innovative capacity by equipping people with the knowledge and skills required by the increasingly dynamic knowledge-based economy. This perspective had a significant impact on the orientation and focus of European RTD policy. Therefore latest Framework Programmes have shifted their emphasis from supply-side factors to diffusion-oriented projects, greater learning skills and increased knowledge diffusion among Europeans.

**Background of IST-RTD Programmes**

Research in information and communication technologies within Framework Programmes was initiated with ESPRIT in FP1. In FP2, RACE (on communications technologies) and three individual Telematics research programmes were added. The latter three merged under FP3, whilst RACE and ESPRIT continued to exist as separate programmes. In FP4, ESPRIT and Telematics were carried on, while a new programme on advanced communications technologies and services (ACTS) was included in the framework. These three research activities were brought together and extended under FP5 (1999-2002) into the “Information Society Technologies” (IST) programme, to provide a single and integrated programme that reflected the convergence of information processing, communications and media. In the 6th Framework Programme, which was approved in 2002 and was run from 2003 to 2006, Information Society Technologies was one the seven priority themes within the specific programme for “Integrating and strengthening research and technology developments in the European Research Area”. Finally, ICT research remains one of the key themes of the EU’s Seventh Framework Programme for Research and Technological Development, which will fund research across Europe from 2007-2013.

Thus, European Commission has made considerable investments in research and technological development in the area of Information Society Technologies since the introduction of the FPs. Table 1 designates that the budget approved between FP4 and FP6 for IST research is the largest one compared to the other thematic priorities. Furthermore, a total of € 9.1 billion is approved for funding information and
communication technologies over the duration of FP7 making it the largest specific programme of FP7 (with 64% of the total budget).

Table 1: Budget between FP4 and FP6 (in million euros)

<table>
<thead>
<tr>
<th>Research Area</th>
<th>FP4</th>
<th>FP5</th>
<th>FP6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information society (IT, communications, telematics)</td>
<td>3,668</td>
<td>3,600</td>
<td>3,984</td>
</tr>
<tr>
<td>Quality of life (life sciences, biotechnology, biomedical research)</td>
<td>1,709</td>
<td>2,413</td>
<td>3,267</td>
</tr>
<tr>
<td>Competitive and sustainable growth (industrial and manufacturing technologies including aeronautics)</td>
<td>2,383</td>
<td>2,705</td>
<td>2,611</td>
</tr>
<tr>
<td>Environment (including transport)</td>
<td>1,176</td>
<td>1,083</td>
<td>1,439</td>
</tr>
<tr>
<td>Energy (nuclear and non-nuclear)</td>
<td>2,412</td>
<td>1,781</td>
<td>1,725</td>
</tr>
<tr>
<td>Improving human potential</td>
<td>889</td>
<td>1,280</td>
<td>3,101</td>
</tr>
<tr>
<td>Other</td>
<td>927</td>
<td>838</td>
<td>1,756</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13,164</strong></td>
<td><strong>13,700</strong></td>
<td><strong>17,883</strong></td>
</tr>
</tbody>
</table>


**Strategic goals of IST in FP4, FP5, FP6**

The ACTS, Telematics and ESPRIT IV Programmes in the FP4 had a common strong user orientation as well as a focus on the development of applications with a view of implementation and commercial exploitation in a short period after the termination of the funded projects. The IST programme in FP5 had a stronger focus on long and medium term research and a clearer engagement for pre-competitive technology development. Thus, a major difference between FP4 and FP5 were the lower expectation for commercial deployment soon after the end of projects. Furthermore a significant difference between FP5 and previous programmes was the enhancement of a closer articulation between research and policy needed for a coherent and inclusive information society. However other fundamental objectives, such as to promote the development of European solutions and technologies, to enhance European competitiveness and economic development, to encourage the cooperation of companies, universities and research laboratories from different European countries in pursuit of common technological goals remained more or less the same between.

By bringing together researchers from all over Europe and by making it possible to pull together diverse and complementary technical resources and capabilities of different actors, the FPs have contributed significantly to the development of a large
number of networks even extending formal collaboration. Therefore, EU cooperative research projects have a decisive impact on the strengthening of the knowledge base, skills and networking links of the RJVs participants.

The political climate which influenced the objectives of the IST priority in FP6 was quite different from FP5, since at that time the foundations for the European Research Area had been laid and the Lisbon and Barcelona Councils had set out a basis for making Europe the world's most competitive and dynamic economy.

The IST Thematic Priority objectives exhibited a clear shift toward longer-term technology development and a major change in the instruments for its implementation. More specifically, two new funding mechanisms, Integrated Projects (IP) and Networks of Excellence (NoE) were introduced in FP6 alongside with the traditional instruments. Both of them were aimed at structuring and integrating European research better than the earlier mechanisms. This was mainly to result from a radical increase in the scale and size of the research projects, and in terms of consortium size.

Integrated Projects aim to support \textit{objective-driven research}, where the primary deliverable is knowledge related to new products, processes, services etc. The goal was to bring together critical mass of resources in order to either increase Europe’s competitiveness or address major societal needs. They have limited internal flexibility as the overall work flow is laid from the beginning. The coordinating organization has a key role and mediates participation and has therefore increased bargaining power. Integrated Projects are likely to involve a wide range of partners from the research and business communities.

Networks of Excellence are multi-partner projects aimed at strengthening European excellence on a research topic by networking the critical mass of resources and expertise. They are more likely to involve publicly-supported research organization and include few companies as they provide little financial incentive to participate. They have less hierarchical structures and they could be a formidable vehicle for building mobility networks, especially among young researchers.
Methods

Description of the dataset

This paper’s dataset is drawn from the most recent version of the STEP to RJVs database which is developed and maintained by LIEE/NTUA. This is an extensive database presently including detailed information on all collaborative cross-national research projects funded by the European Commission in FP1 to FP6. The primary information source for the database construction is CORDIS (CORDIS search 2007), the official information service of the European Commission. The main difficulty encountered during the database construction was the inconsistency of raw data retrieved from CORDIS. Apart from correcting incoherent spelling in organizations names, particular attention was given to cleaning in detail the poor quality data on organization types. Furthermore, wherever possible, missing information regarding the geographical/regional location of organizations was added in the dataset.

The present paper’s dataset is part of the STEP to RJVs database and comprises RJVs belonging to the 4th, 5th and 6th Framework Programmes (1994-2006) in the area of Information and Communication Technologies. More specifically the RJVs under study belong to ESPRIT 4, TELEMATICS 2C and ACTS Programmes of the 4th FP and the IST thematic priority of the 5th and 6th FPs and involve at least one firm participant in the project consortium. The database contains information on all IST projects pertaining to the 4th and 5th FPs, while the available information for FP6 includes all projects with starting date in December 2006.

Table 2: Descriptive statistics of the database

<table>
<thead>
<tr>
<th></th>
<th>FP4</th>
<th>FP5</th>
<th>FP6</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of organizations</td>
<td>4,879</td>
<td>7,406</td>
<td>3,879</td>
</tr>
<tr>
<td>No of participations</td>
<td>9,302</td>
<td>16,381</td>
<td>10,582</td>
</tr>
<tr>
<td>No of projects</td>
<td>1,416</td>
<td>2,206</td>
<td>799</td>
</tr>
<tr>
<td>Average duration (months)*</td>
<td>25.65 (8.5)</td>
<td>26.3 (8.82)</td>
<td>32.85 (8.07)</td>
</tr>
<tr>
<td>Average budget per project (million €)</td>
<td>2.25 (3.72)</td>
<td>2.68 (2.05)</td>
<td>3.6 (6.45)</td>
</tr>
<tr>
<td>Average funding per project (million €)</td>
<td>1.08 (2.17)</td>
<td>1.5 (1.04)</td>
<td>2.2 (3.57)</td>
</tr>
<tr>
<td>Average no of participants per project</td>
<td>6.57 (4.26)</td>
<td>7.43 (5.05)</td>
<td>13.24 (9.11)</td>
</tr>
<tr>
<td>Average project number per participant</td>
<td>1.9 (3.15)</td>
<td>2.2 (5.09)</td>
<td>2.7 (5.6)</td>
</tr>
</tbody>
</table>

* Standard deviations in parenthesis
In total, the dataset contains detailed information on 4,421 research projects and 12,844 different participating entities. Table 2 shows that there is a considerable increase in the number of projects and participating organizations between FP4-FP5 and FP5-FP6 reaching 55.8% and 76.1%, respectively. The 5th FP represented a major change compared to FP4 since it brought together the previously separate ESPRIT, ACTS and TELEMATICS Applications Programmes into one single Programme. Furthermore, the IST priority was the prominent priority in financial terms in the FP5 (see Table 1). Therefore, the resulting high participation of more organizations in a greater number of projects may be expected.

Nevertheless, the picture is changing between FP5 and FP6. Compared to FP5, FP6 is characterized by a smaller number of projects that are larger in size i.e. involve more organizations. The bigger size of projects in FP6 can be attributed to the IP and NoE instruments which include on average 21 and 26 partners respectively. In addition, average funding per project is higher in FP6 than in FP5 as more money is distributed to fewer organizations.

For the needs of the database, participating organizations were distinguished into the following types (i) “firm” (combining industry and consultancy); (ii) “university” (all educational institutions); (iii) “research centre” (various research foundations) and (iv) “other” (combining government, hospitals, libraries museums, city councils etc.).

![Figure 1: Distribution of entity types in the FP networks](image-url)
The entities that are included in the “other” category are mainly users—rather than developers—of the information and communication technologies. This conclusion is reinforced further by the finding that the vast majority of these entities join RJVs only once.

As shown in Figure 1, the majority of participating entities in all FPs are firms. Their presence varies from 68% in FP4 to 59% in FP6. This may be partly attributed to the fact that we have selected RJVs with at least one firm in the consortium. The presence of universities is almost doubled in FP6 mainly through their participation in IPs and NoEs which accounts for the 60% of their total involvement in FP6. The right part of Figure 1, which depicts participation intensity by organization type, designates that the participation intensity of educational institutions has increased across FPs (from 17% in FP4 to 36% in FP6) while the opposite holds for industry, since the relevant percentages reveal a decreasing intensity across FPs (from 63% in FP4 to 39.8% in FP6).

Figure 2 indicates the returning and new actors in FP5 and FP6. It is obvious that the majority of organizations participating in FP5 are new, while in FP6 this picture has changed. While in FP5 the percentage of newcomers is almost 86% of the total population of participating entities, in FP6, new organizations account only for 41.6% of the total. In both FPs the majority of new organizations are firms (52.66% in FP5 and 32.74% in FP6). In FP6 the share of returning organizations is increased in all types of actors. More specifically, almost all universities and research centres that had participated in previous FPs seem to renew their presence in FP6. Furthermore, the percentage of returning firms between FP4 and FP6 is roughly tripled. These organization overlaps between FPs indicate the development of a core of actors (mainly universities and firms) exhibiting more stable relationships than others and thus acquiring a more prominent position in the FP networks.
Table 2 shows that the average number of projects per participant varies from 1.9 in FP4 to 2.7 in FP6. However, not all actors are equally active in the FPs (Caloghirou et al. 2004, Barber et al, 2006), which is also the case of the IST programmes as shown in Figure 3. In all three FPs the large majority of actors participate in just one collaborative research project. Nevertheless there is a very small share of organizations that exhibits a large number of participations. More specifically, the share of entities that exceeds 20 memberships in each FP is 0.6%, 1% and 1.4% respectively. In addition, as indicated in Figure 4, the majority of these active actors, especially in FP5 and FP6 are universities.

Figure 2: Returning and new entities by organization type
The above findings may suggest that some organizations have a more prominent position in the network compared to others. Nevertheless these actors cannot be identified by simple descriptive statistics but by examining the structural characteristics of the FP networks exploiting the relational information gathered in our dataset. This kind of analysis is provided in the next sections.
The social network analysis tool

In general, from a collaborative perspective, networks can be defined as a set of actors linked by a set of social and business relationships that create strategic inter-organizational opportunities. More specifically, in the case of the examined RJV networks, organizations such as firms, universities and research institutes get connected by cooperative relationships that allow them to access new resources to augment their core capabilities and complementary assets and to engage in new learning/innovative activities to develop new ICT technologies.

We employ social network analysis tools to study our RJV networks. Social network analysis has developed over several decades to provide insights into the dynamics concerning the direct and indirect interactions among agents. However, recent research on the structure and evolution of networks emerging from physics and biology communities have regenerated interest in applying network tools in many types of network activities including research collaborations (Barabási et al., 2002). When network analysis is used to study networks formed by actors engaged in collaborative activity it can shed light into the efficiency of operations and knowledge diffusion as well as into the role of different actors. These characteristics may impact the efficiency and effectiveness of funding and therefore the research outcome. Moreover, they may constitute a crucial step to the evaluation of research policies and the benchmark of future policies in the area of ICT technologies.

The participants in a research joint venture are the structural variables or nodes that allow the analysis of the activities as a system. The interaction within the network context brings to light the dynamics of exchange among participating organizations that in networking theory is more than the sum of the individual parts.

The networks formed by the organizations participating in the RJVs we are studying can be characterized as an affiliation network. An affiliation network consists of information about subsets of actors who participate in the same social activity or event (group, club etc.). In the case of the present FP networks, participating organizations are joined together by their membership in the same research projects. They are, basically, bipartite structures: the information they contain is most completely represented as a graph consisting of two kinds of vertices, one representing the actors and the other representing the groups. Edges then run only
between vertices of unlike kinds, connecting actors to the groups to which they belong.

Affiliation networks are often represented simply as unipartite (one-mode) graphs of actors joined by undirected edges, i.e. two organizations participating in the same RJV project joined by an edge. This network representation does not take into account the number of shared memberships between two companies and therefore does not allow for comments on tie strength. Although the representation of an affiliation network (an essentially two-mode network) as a unipartite graph may lead to the loss of certain information, the methods for studying two-mode affiliation networks are less developed than are methods for studying one-mode networks (Wasserman and Faust, 1994).

![Bipartite graph of organizations and research projects](adapted from Newman et al. 2002)

Figure 5: Bipartite graph of organizations and research projects (adapted from Newman et al. 2002)

Our analysis will be based on the unipartite graphs of organizations involved into research partnerships. In the top part of Figure 5 is represented the bipartite graph of 12 organizations participating in A to D projects. Each organization is linked to the project it participates in with a line. In the bottom of the figure is presented the one-
mode projection of the same network onto just participating entities. Finally, each individual project in this database is considered as a completely connected sub graph. This is an idealized representation of the network, but it is considered as a reasonable approximation of the actual network structure except for very large projects. As the average number of participants per project does not exceed 13 (see Table 2), we may assume the present representation to be more accurate than the other idealized type of a star structure, in which each participating entity is only linked to the project coordinator and no direct connection exists between partners.

**Structural characteristics of FP networks**

The assessment of network properties depends on certain assumptions related to the nature of interactions among nodes (organizations). Since we assume that network ties exhibit equal weights and exist between all pairs of organizations participating in an RJV we use the default assumption of a clique. The implication for the FP networks examined is that all members of a project consortium are directly connected to all other members of the same consortium.

A number of indicators representing the topological features of the IST networks constructed under the 4th, 5th and 6th FPs are shown in Table 3.

**Table 3: Structural features of FP networks**

<table>
<thead>
<tr>
<th></th>
<th>FP4</th>
<th>FP5</th>
<th>FP6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>4,879</td>
<td>7,406</td>
<td>3,879</td>
</tr>
<tr>
<td>Edges</td>
<td>35,694</td>
<td>73,309</td>
<td>80,437</td>
</tr>
<tr>
<td>No. of components</td>
<td>60</td>
<td>131</td>
<td>7</td>
</tr>
<tr>
<td>Giant component (size)</td>
<td>4,618</td>
<td>7,038</td>
<td>3,854</td>
</tr>
<tr>
<td>% of total network</td>
<td>94.7</td>
<td>95.1</td>
<td>99.2</td>
</tr>
<tr>
<td>Density</td>
<td>0.003</td>
<td>0.0027</td>
<td>0.0107</td>
</tr>
<tr>
<td>Stand. Deviation (density)</td>
<td>0.0547</td>
<td>0.0517</td>
<td>0.1029</td>
</tr>
<tr>
<td>Characteristic path length</td>
<td>3.39</td>
<td>3.15</td>
<td>2.373</td>
</tr>
<tr>
<td>Diameter</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Clustering coefficient</td>
<td>0.854</td>
<td>0.842</td>
<td>0.846</td>
</tr>
<tr>
<td>Mean degree</td>
<td>14.69</td>
<td>19.8</td>
<td>41.47</td>
</tr>
<tr>
<td>Stand. Deviation (degree)</td>
<td>21.99</td>
<td>38.104</td>
<td>70.903</td>
</tr>
<tr>
<td>Normalised degree (avg)</td>
<td>0.3</td>
<td>0.268</td>
<td>1.069</td>
</tr>
</tbody>
</table>

There are various indicators that measure the social distance among organizations participating in a network.
An important property of a graph representing a network is whether or not it is connected. A graph is connected if there is a path between every pair of nodes present in the graph. A component is formally defined as the maximal connected sub-graph. A sub-graph, just like a graph, is connected when all of its points can ‘reach’ one another through one or more paths, but have no connections outside the sub-graph.

A sequence of lines in a graph, where each node and each line are distinct, is called a path. The length of a path is the number of lines it contains, or the number of steps that separate two nodes. Paths are useful to measure distance between nodes in a graph. The geodesic distance is defined as the length of the shortest path between two organizations in the network. The average geodesic distance in a connected graph is the characteristic path length. The eccentricity of a node is the maximum geodesic that separates it from another one. The graph diameter is defined as its maximum eccentricity.

All networks examined are found to be tightly interconnected. The examination of the number of nodes in the largest component of the graphs representing the three networks designate that they are highly connected. The giant or largest components found, cover a very extensive area of the relevant graphs and contain 4,618 organizations in FP4 (94.7% of all organizations), 7,038 organizations in FP5 (95.1%) and 3,854 organizations in FP6 (99.2%). In addition, all the remaining components are very small. These findings point out that the vast majority of organizations participating in these EU funded projects are, directly or indirectly, interconnected via collaboration. Therefore it can be assumed that these programmes may have the potential to promote networking activity in the specific IST areas. In particular, FP6 seems to be more tightly networked and interconnected than earlier IST networks. The increased interconnectivity in the IST FP6 network may be partly attributed to the large number of participating organizations per project under the Integrated Projects and Networks of Excellence instruments.

Given the size and the resulting significance of the three giant components the analysis from this point onwards will be restricted to them.

Table 3 also shows that the characteristic path length is practically decreasing from FP4 to FP6. Looking at network density- the proportion of potential links that have been actually observed- it is also noticed that the IST-FP6 network appears to be denser compared to the other two. The degree of an organization is a measure of the
“activity” of the actor it represents and it can be defined as the number of its directties with other partners. The average degree of organizations that form the IST networks in FP4 and FP5 are approximately the same. Nevertheless, this indicator, increases sharply for organizations belonging to the FP6 network.

All the above examined measures indicate that the three RJV networks exhibit high interconnectivity. Furthermore, the FP6 network appears to be more closely connected than the other two, therefore the “distance” between any two organizations participating in this network is shorter than it has been in the earlier two frameworks.

**Degree distribution**

A property that has attracted attention in a wide range of different networks (for example, the world wide web (WWW), the Internet, research collaborations based on co-authorship of papers) is the degree distribution, $P(k)$, which estimates the probability that a randomly selected node has $k$ links (Barabási et al., 2001).

Real-world social networks differ from uniform random graphs with regard to several statistical parameters, especially node connectivity distribution or degree distribution. Indeed in random graphs, links between agents are present with a constant probability $p$ and degree distributions follow a Poisson law (bell-shaped distribution) whereas empirical social networks exhibit power-law, highly skewed degree distributions. The degree distribution for the giant components of the networks developed under the different FPs is depicted in Figure 6.

![Figure 6: Degree distribution](image)

*(Figure 6: Degree distribution) (i) raw data plotted on a double logarithmic scale -left hand side; ii) distribution with logarithmic binning –right hand side)*
The above histograms indicate that the distributions are highly skewed, as the majority of organizations have a small number of direct links, whereas only a small proportion of actors demonstrate a large number of connections. Such degree distributions follow a power law \( P(k) \sim k^{-\gamma} \) with scaling exponent \( \gamma \) taking a value between 2.1 and 4 (Barabási and Albert, 1999): it is represented by a gradually decreasing curve that allows ‘rare’ events (nodes with a few connections) to coexist with many, albeit small events, i.e. nodes with a few links.

This finding shows that the networks connectivity is controlled by a few important nodes, or hubs, that tend to have a large number of ties. This phenomenon, which is called preferential attachment, puts forward the argument that actors do not interact at random but instead according to heterogeneous preferences for other nodes. More specifically, under this assumption, it is suggested that there is a higher probability that a new node will get connected to a node already exhibiting a large number of connections. Thus, highly connected nodes become even more connected generating a power-law degree distribution.

In order to test this hypothesis, we first consider the distribution of degrees of participating entities in the RJV network during the period 1994-1998 (FP4). Then we calculate the number of new links established in the period 1999-2002 (FP5). The results (see Figure 7) seem to support the above hypothesis as they indicate that actors with a large degree in the first period obtained a disproportionately higher number of new links in the second period. For instance, organizations with up to 20 previous links, which represent the 20.7% of all entities participating in the FP4 network, acquired only 14.8% of all new connections established in the 2000-2002 period. However, organizations with a large number of previous links (more than a 100) accounted for only 2.8% of all organizations present in the network in the 1994-1998 period and attained approximately 19% of all incoming links in the second period. Furthermore, the same observations hold (see right hand side of Figure 7) if we consider the distribution of degrees of participating entities during the period 1994-2002 (FP4 and FP5) and we calculate the number of new links established in the FP6 period.

---

2 The relative probability of new links which represents the y axis in the Figure 7 is calculated by the ratio between the proportion of new links added to organizations with k previous links, and the proportion of actors with k previous links on all the organizations present in the network just before the addition of the link (Breschi, and Cusmano, 2004)
The analysis performed up to now points out the vital role of a few important actors in maintaining the network connectivity in each FP. But how fragile are the networks to the removal of these specific actors? An answer, at least partly, to that question has to do with the way they influence networks topological characteristics, such as characteristic path length or size of the largest component.

The resilience of a network is its vulnerability to the removal of nodes. If the removal of one or more nodes results in a considerable increase in the distance between nodes (or indeed causes some nodes to become disconnected) then the efficiency of the network (at least as a communications network) will be diminished.

In our analysis we have investigated how several network properties are affected by the removal of the most important organizations and the removal of the same fraction of organizations in a random way. More specifically in Figure 8 are presented the changes in largest component and the average distance as a function of the fraction \( f \) of the removed nodes. Our findings indicate that all three networks examined exhibit a high degree of robustness to the random removal of a big number of the participating organizations. Thus, even if 10% of all organizations is removed from the networks their connectivity, and therefore the communication paths among the remaining nodes remain practically unaffected. The largest component still accounts for a very high proportion of the remaining organizations (84% in FP4, 85% in FP5 and 89% in FP6) and average distance or characteristic path length are stable. The networks robustness can be attributed to their extremely inhomogeneously
connectivity distribution. Because of the power-law distribution the random removal of nodes takes out the ones with small connectivity as they are much more plentiful than hubs. The elimination of these nodes will not disrupt significantly the networks topology, because they maintain few links compared to hubs.

The results also show that our networks are quite “vulnerable” to the elimination of highly connected nodes. When the most connected nodes are eliminated the networks average distance is rapidly growing. More specifically, if 10% of these nodes are removed the average distance size is doubled. Moreover the giant component size drops considerably (to approximately the 42% in FP4, 31% in FP5 and 50% in FP6 of the remaining organizations) when 10% of the most central nodes are taken off the networks.

![Network Resilience](image)

*Figure 8: Network resilience*

This vulnerability to the elimination of the prominently connected nodes indicates their important impact on networks connectivity. Their removal changes significantly the networks topology and decreases the ability of less connected nodes to communicate effectively with each other.
Small-world property

In this section we will examine whether the RJV networks under study exhibit a small-world property. Small worlds perform well as structures aiming at knowledge sharing and transmission and innovation support (Cowan, 2005; Cowan and Jonard 2003; Baum et al. 2003). Therefore, this analysis will enable us to judge the overall efficiency of these networks as mechanisms for the diffusion and exchange of new technological knowledge.

Following Watts (1999) we identify the presence (or absence) of the small-world behaviour in our network using the combination of two measures, the characteristic (average) path length $L$ and the clustering coefficient $C$.

The clustering coefficient estimates the probability that two neighbouring nodes of a given node are neighbours themselves and is a measure of local network structure. In the present networks it relates to the probability that if organization A collaborates with organizations B and C then B and C are collaborators as well. The clustering coefficient ($C_i$) of a node can be defined as the ratio between the total number of the edges connecting its nearest neighbours and the total number of all possible edges between all these nearest neighbours. The clustering coefficient $C$ for the network as a whole is the average $C_i$ over the number of nodes $n$. Therefore the clustering coefficient indicates how many of a node’s collaborators are, on average, disposed to collaborate with one another.

By definition, $L$ is a measure of the global network structure, since determining the shortest path length between any two organizations necessitates information about the topology of the entire network. Characteristic path length gives an indication of the network efficiency regarding knowledge diffusion. Thus high values of $L$ indicate that resources, such as information or knowledge, must surpass a large number of intermediaries to travel between organizations in an RJV network.

In order to decide whether a network has the property of being a small world, the values of these two parameters are compared with the values of the respective parameters of a completely random network with the same number of nodes ($n$) and average number of ties ($k$) per node. For a random network, the clustering coefficient is calculated as $k/n$ and the characteristic path length as $\ln(n)/\ln(k)$ (Watts, 1999). If a
network is a small world it must exhibit a much larger clustering coefficient than that of a random network ($C >> C_{\text{random}}$), and at the same time a characteristic path length that is approximately equal to that of a random network ($L \sim L_{\text{random}}$). In other words, the small world property is valid when a network is much more highly clustered than a comparable random network, but the average distance among its nodes is analogous to that of a random network.

Table 4 compares the actual (observed) network characteristics with those of a random network for each FP. Random networks were constructed in each case using similar values for the number of nodes and the average degree to those actually observed.

Table 4: FP networks: small-world property

<table>
<thead>
<tr>
<th>FP</th>
<th>Network</th>
<th>Characteristic path length</th>
<th>Clustering coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th</td>
<td>Actual</td>
<td>3.39</td>
<td>0.854</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>3.164</td>
<td>0.003</td>
</tr>
<tr>
<td>5th</td>
<td>Actual</td>
<td>3.15</td>
<td>0.842</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>2.984</td>
<td>0.003</td>
</tr>
<tr>
<td>6th</td>
<td>Actual</td>
<td>2.373</td>
<td>0.846</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>2.218</td>
<td>0.011</td>
</tr>
</tbody>
</table>

From Table 4 it could be concluded that all three RJV networks exhibit a small world property, as actual and random networks have approximately equal path lengths, but actual networks appear to have much larger clustering coefficients than the comparable random networks. This finding, which is in line with the results of two more studies concerning research partnerships under the 3rd and 4th EU Framework Programmes (Breschi and Cusmano, 2004; Verspagen, 2006), implies that the networks of R&D consortia we are examining seem to be effective mechanisms for the transmission of information and knowledge.

Central actors

Our empirical analysis so far has highlighted the fact that there is a core of significant actors gaining in connectedness and significance over time by repeated participation in RJVs and the mechanism of preferential attachment. These actors are usually located in strategic or central positions within the three networks and therefore are
those that are extensively involved in relations with other actors (Burt, 1980; Wasserman and Faust, 1994). They may also have greater access and control over resources and in consequence they are likely to be highly associated with innovative activity (Powel et al., 1996, Rogers, 1995, Bell, 2005).

We next focus on the specific top ten key players of each network we are investigating (Table 5). To shed light on their importance we operationalize their prominence using four centrality measures for each organization, namely degree centrality, eigenvector centrality, betweenness centrality and closeness centrality.

Each of these four measures quantifies a different aspect of centrality:

Although degree centrality is one of the simplest centrality measures it is also a highly effective measure of prominence or power. In many social settings actors exhibiting multiple connections with other actors tend to be more powerful.

A more sophisticated version of degree centrality is eigenvector centrality. This index does not only address the quantity but also the quality of connections an actor has. In this way, connections to actors who are themselves well connected are more influential than connections to poorly connected actors. Therefore having a large number of connections does not necessarily give advantage to a specific actor, it also matters to whom it is connected to. The eigenvector centrality of node \( i \) is the sum of its connections to other nodes, weighted by their degree centrality.

Betweenness centrality refers to the number of times an actor is located on the geodesic path between two other actors. If the geodesic, between two nodes \( n_2 \) and \( n_3 \), that is the shortest path between these two nodes has to go through two other actors \( n_1 \) and \( n_4 \), then we could state that the two nodes included in the geodesic might have control over the interaction between \( n_2 \) and \( n_3 \) (Wasserman and Faust, 1994). In a network where information is diffused, an organization that exhibits a high degree of betweenness centrality can act as a gatekeeper and therefore has the potential to control the flows of information between those other organizations (Freeman, 1979; Knoke and Kuklinski, 1982). The betweenness centrality of node \( i \), is based on counting how often it is located in between a pair of organizations along all the possible paths connecting these two nodes, for all possible pairs.

Closeness centrality focuses on how close an actor is to all other actors in a network, indicating that actors occupying central network positions can quickly communicate
information to others (Wasserman and Faust, 1994). Closeness centrality of node $i$ is the inverse sum of distances to all other nodes. Closeness centrality is lower for nodes that are more central in the sense of having a shorter network distance on average to other nodes.

The above mentioned centrality indices were calculated for all organizations and a synthetic index has been produced by the joint rankings of organizations in terms of these four indicators.

Table 5 shows the ten more central organizations per FP. While in FP4, half of the most central organizations are firms, in the consequent FPs universities and research centers move up the ranking and firms have a marginal presence in the top ten (one firm in FP5 and 2 firms in FP6). Some organizations assume central positions in more than one FPs indicating that there is a continuity in their research efforts within FPs and furthermore that their power is increased through the years. For example, Fraunhofer Research Institute is the fourth more central organization in FP4 but it ranks first in FP5 and FP6, while the National Technical University of Athens ranks 7th in the top ten list in FP4 and FP5, it moves up the ladder to the 4th position in FP6.
<table>
<thead>
<tr>
<th>Ranking</th>
<th>Organisation Name</th>
<th>Type</th>
<th>Country</th>
<th>Score</th>
<th>Organisation Name</th>
<th>Type</th>
<th>Country</th>
<th>Score</th>
<th>Organisation Name</th>
<th>Type</th>
<th>Country</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Siemens A.G.</td>
<td>IND</td>
<td>GER</td>
<td>4</td>
<td>Fraunhofer Gesellschaft zur Forderung der Angewandten Forschung E.V.</td>
<td>RES</td>
<td>GER</td>
<td>4</td>
<td>Fraunhofer Gesellschaft zur Forderung der Angewandten Forschung E.V.</td>
<td>RES</td>
<td>GER</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Intracom S.A.</td>
<td>IND</td>
<td>GRE</td>
<td>12</td>
<td>Centre National de la Recherche Scientifique</td>
<td>RES</td>
<td>FRA</td>
<td>8</td>
<td>Centre National de la Recherche Scientifique</td>
<td>RES</td>
<td>FRA</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Centro Studi e Laboratori Teleunicazioni S.P.A. (CSELT)</td>
<td>IND</td>
<td>ITA</td>
<td>17</td>
<td>Universidad Politecnica de Madrid</td>
<td>EDU</td>
<td>ESP</td>
<td>18</td>
<td>Ecole Polytechnique Federale de Lausanne</td>
<td>EDU</td>
<td>SWI</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Centre National d'Etudes de Telecommunications (CNET)</td>
<td>RES</td>
<td>FRA</td>
<td>20</td>
<td>Consiglio Nazionale delle Ricerche</td>
<td>RES</td>
<td>ITA</td>
<td>18</td>
<td>National Technical University of Athens</td>
<td>EDU</td>
<td>GRE</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>Forderung der Angewandten Forschung E.V.</td>
<td>RES</td>
<td>GER</td>
<td>25</td>
<td>Ecole Polytechnique Federale de Lausanne</td>
<td>EDU</td>
<td>SWI</td>
<td>18</td>
<td>Consiglio Nazionale delle Ricerche</td>
<td>RES</td>
<td>ITA</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Universidad Politecnica de Catalunia</td>
<td>EDU</td>
<td>ESP</td>
<td>26</td>
<td>Institut National de Recherche en Informatique et en Automatique</td>
<td>RES</td>
<td>FRA</td>
<td>25</td>
<td>Kungliga Tekniska Hogskolan</td>
<td>EDU</td>
<td>SWE</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>National Technical University of Athens</td>
<td>EDU</td>
<td>GRE</td>
<td>34</td>
<td>National Technical University of Athens</td>
<td>EDU</td>
<td>GRE</td>
<td>26</td>
<td>Institut National de Recherche en Informatique et en Automatique</td>
<td>RES</td>
<td>FRA</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>Instituto de Engenharia de Sistemas e co</td>
<td>IND</td>
<td>POR</td>
<td>36</td>
<td>Katholieke Universiteit Leuven</td>
<td>EDU</td>
<td>BEL</td>
<td>29</td>
<td>Telefonica Investigacion y Desarrollo sa Unipersonal</td>
<td>IND</td>
<td>ESP</td>
<td>39</td>
</tr>
<tr>
<td>9</td>
<td>Nederlandse Philips B.V.</td>
<td>IND</td>
<td>NED</td>
<td>42</td>
<td>Universidad Politecnica de Catalunia</td>
<td>EDU</td>
<td>ESP</td>
<td>35</td>
<td>France Telecom S.A.</td>
<td>IND</td>
<td>FRA</td>
<td>42</td>
</tr>
<tr>
<td>10</td>
<td>Inter University Microelectronics Center</td>
<td>RES</td>
<td>BEL</td>
<td>47</td>
<td>Siemens A.G.</td>
<td>IND</td>
<td>GER</td>
<td>41</td>
<td>Universidad Politecnica de Madrid</td>
<td>EDU</td>
<td>ESP</td>
<td>43</td>
</tr>
</tbody>
</table>

Note: IND stands for Industry RES for Research centre EDU for Educational institutions
To test whether these observations mirror a general trend in the data larger sub-groups are used. Since we are interested in the core actors of each FP the sub-groups included the top 1% and top 5% of the organizations on the basis of the joint ranking. Figure 9 reports the distribution of central organizations by organization type for the three FP networks. The resulting distributions confirm the trend identified among the top 10 central organizations, i.e. that the role of universities and research centres as central actors or hubs is very important in the IST thematic priority and moreover that their role is strengthened from FP4 to FP6 (for example, in the top 5% distribution universities account for the 30% of the most central organizations in FP4 and the 61% in FP6).

![Figure 9: The top 1% and top 5% actors per FP](image)

**Discussion of results**

The context for ICT research in Europe has changed radically during the last fifteen years. With increasing global competition no single EU country or organisation can afford the cost of building the required know-how, capabilities and complementary assets to master increasingly complex technology chains. EU –funded IST research programmes can be an effective mechanism to foster the pan-European industry-academic collaboration and therefore advance the development of networks needed to integrate ICT goods and services and to develop the EU and international standards that enable them to work together.
This paper attempts to examine the collaborative networks, formed under the 4th, 5th and 6th EU Framework Programmes, in relation to the Information Society Research and Technology Development. Participants in the specific RJVs were considered as project teams that create networks to share knowledge and conduct research. These collaborative networks-different institutions that join together for a time-limited, specific research purpose-are increasingly recognized as an important tool for knowledge exchange and innovation. The network effects of EU RJVs seem to be clearly demonstrable in many cases. For example, although difficult to quantify, developing cooperation between universities and firms, is likely to be of considerable long-term importance to the performance of European industry (Laredo, 1995). The formation of regional RTD networking activities can also be considered an important feature (Barker and Cameron, 2004). However, little empirical work on the overall structure, dynamics and evolution of networks emerging in the context of EU Framework Programmes has yet been produced (Breschi and Cusmano, 2004).

The present paper is an initial contribution to this direction as the examination of the structural features of the underlying networks is a very crucial issue in order to understand the function of a complex system and how it affects the spreading of information, the process of knowledge transmission etc. Moreover, the identification and description of networks that have been formed in previous FPs may act as an important benchmark for the future policy design.

The empirical evidence we have presented in the previous section indicates that our networks, which are actually a part of the greater network including all the RJVs conducted under the 4th, 5th and 6th FPs, appear to exhibit similar topological characteristics with the network that has been formed by the research projects of the 3rd and 4th FPs (see Breschi and Cusmano, 2004 and Barber et al. 2006). In particular, our findings put forward that the specific IST networks are rather dense, pervasive and robust. Moreover the structural features of the FP6 network point out that it is even denser and more highly connected than the previous two (FP4 and FP5), indicating that the IST network as a whole has gained in connectivity through the years.

The greater the density in a network is, the greater the connectedness of its members. Information in a dense network will move faster and more efficiently as a result of the many connections and potential lines of allocation (Coleman, 1990). Despite the high
connectivity that our networks exhibit, it seems that they are strongly dependent on a core of central actors. The organizations that assume central positions in a network generally serve to organize research and to facilitate exchange of knowledge among more peripheral actors. Furthermore, the quantity and quality of knowledge creation and diffusion within the entire network is evidently dependent on the resources and technological capabilities deployed by these important organizations. Their focal role concerning the overall network connectivity becomes even more prominent as our empirical analysis confirms that the three networks pertaining to each FP are extremely vulnerable to the removal of these few important actors. Their elimination changes significantly the networks’ topology and decreases the ability of less connected nodes to communicate effectively with each other.

Another important finding is that the “leading” role of these focal organizations seems to be a phenomenon which appeared from the early stages of the IST network formation and has strengthened over time. In other words, they are organizations that are early connected to the network (in FP4) which they eventually become even more connected and central through their repeated participation and the mechanism of preferential attachment. These actors are mainly prestigious universities (mainly technical departments) and research institutes and large-sized industry and technology leaders.

Our analysis also suggests that educational institutions and research centres tend to have a more active and prominent role in the networks examined. It could be argued that the central role of these organizations within the specific networks, which are formed by RJVs that aim at the creation of innovative and complex technological systems, may be expected as these institutions are important generators of new knowledge necessary for the creation of these systems. On the other hand, firms have a less active and stable presence in these networks mainly because their participation is usually not oriented towards the exploitation of research outputs but primarily to the acquisition of new technological knowledge, the setting of the new standards required for the development of new markets etc.

It is obvious that although the role of prominent actors in the three FP networks is highly influential, there are other less focal organizations, such as (for example technologically dynamic small and medium-sized firms) which may bring fresh ideas and new resources essential for the creation of innovative outputs. While, these
networks include a number of innovative SMEs, these firms do not and probably cannot assume central positions. Furthermore, it seems that a large share of dynamic SMEs does not participate at all in EU funded IST programmes. SME participation in IST networks is an issue which calls for further investigation.

Finally, the empirical analysis showed that our network seems to demonstrate the characteristics of a small-worlds network. In contrast to a pure social capital or structural holes perspective our network can therefore, be considered as relatively efficient in relation to knowledge spreading and exchange.

As a suggestion for further work, we propose the analysis of other industries and specific programmes to identify regularities or to discover and explain possible systematic structural differences due to diverse knowledge bases, different R&D priorities etc. Moreover, we should endeavour to better understand the kind and processes of knowledge flows between different organization types in innovation networks.

In addition, network analysis could be complemented by an exploration of the motivations of different actors for participating in EU-funded IST-RTD projects as well as the specific benefits or their market success achieved.

**References**


