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Networked research: European policy intervention in ICTs

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We use social network analysis to evaluate 'behavioural' additionality aspects of public programmes supporting research and development (R&D). The paper appraises empirically the partnership and knowledge networks created around the R&D activities of the Information Society Priority of the Sixth Research Framework Programme of the European Community. These emergent, scale-free networks are found to play an important role in generating and, especially, in diffusing knowledge by attracting key industry actors and by strengthening overall network connectivity through public support. Public policy should try to facilitate the development of more European organisations that can be characterised as global network hubs, on the one hand, and to draw larger numbers of the most dynamic small and medium-sized enterprises (SMEs) into these programmes, on the other, to avoid technological lock-ins and mitigate the resistance or network reorientation toward more productive research areas.

Keywords: technology and innovation studies; network analysis; patent analysis; information and communications technology; strategic alliances

1. Introduction

This paper uses social network analysis to evaluate aspects of public programmes supporting research and development. For the specific empirical analysis, the paper draws on a recent study that appraised the partnership and knowledge networks created locally and globally in relation to the Information Society Research, Technological Development and Demonstration (IST-RTD) programmes of the Sixth Research Framework Programme (FP6) of the European Community.

The typical appraisals of RTD expenditures have tended to concentrate in the past on the additionality of public funding in terms of either the resources added into the system (input additionality) and/or the extra private and social returns obtained (output/outcome additionality). More recently, analysts have also emphasised the sustainable effects beyond the infusion of resources and/or the extraction of outputs that such investments create, such as improving the knowledge, capabilities, organisational structures and strategies of the organisations involved (behavioural additionality). This paper focuses on the latter.

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In today's globally competitive and fast changing environment, most innovations involve the collaboration of several different organisations. The collaborative networks leading to new technologies, products and services are very complex, involving not only diverse kinds of formal contracts, but also informal exchanges of knowledge. In a technological development that involves a greater array of products and processes, systems and components, no single firm can deploy all of the required core capabilities and complementary assets at reasonable cost. In this context, the network serves as *a locus for innovation* (Powell, Koput, and Smith-Doerr 1996) because, for any member, it provides timely access to external knowledge and resources while also valorising internal expertise and expanding learning abilities. A large part of the behavioural additionality of RTD investments is, thus, realised through the partnership and knowledge networks that such investments create.

We have utilised social network analysis to assess several aspects of behavioural additionality in specific IST-RTD programmes. We have investigated whether the projects selected for funding by the first two calls for proposals of FP6 in the IST Thematic Areas 1, 2 and 3 ('Applied IST Research Addressing Major Societal and Economic Challenges', 'Communication, Computing and Software Technologies', 'Components and Micro Systems') during the period 2002–2004 have been effective in supporting network hubs that nurture global knowledge leadership and European cohesion. In RTD networks, hub organisations operate as knowledge depositories and sources of information and ideas. A large-scale empirical analysis using several extensive data sets has been carried out to place the IST-RTD networks within the context of broader global networks of collaborative knowledge relationships that have developed independently of Community funding. In addition, more qualitative information obtained through a series of expert/practitioner interviews was utilised to calibrate some of the results and obtain stakeholder suggestions for policy recommendations. The analysis purported to demonstrate the applicability of social network concepts and analytical tools in appraising the relative global positioning of IST-RTD networks and their effectiveness in creating leading knowledge hubs in selected technological domains.

We were concerned with questions such as:

(1) How are hubs positioned in networks created through IST-RTD funding?
(2) How does it compare to their positioning within the broader global networks in IST?
(3) What may be the role of the new funding Instruments of FP6 – integrated projects and networks of excellence – in facilitating the effectiveness of such knowledge hubs?
(4) To what extent are IST-RTD collaboration networks inclusive of national research networks and key large and small IST enterprises around Europe?

It is found that the examined IST-RTD programmes played an important role in generating and diffusing knowledge by managing to attract key industry actors and by creating and increasing network connectivity. The paper argues that public policy should try to facilitate the development of more European organisations that can be characterised as global network hubs and to draw larger numbers of the most technologically dynamic small and medium-sized enterprises (SMEs) into these programmes.

The rest of the paper is structured as follows. Section 2 provides the context of the study. It first summarises key features of the Framework Programme (FP) and of its IST priority and then illustrates the rationale for a network approach to evaluating IST-RTD programmes. Section 3 provides a description of the adopted methodology and data. Section 4 reports the main findings related to the role of IST-RTD funding in creating and sustaining knowledge hubs, the relative importance of these hubs in the global IST network, the role of the new funding instruments (integrated projects and networks of excellence) in supporting and extending the network, and the inclusiveness of core national research organisations. Finally, Section 5 summarises the results and offers policy implications.

2. The framework programme as a networking environment

The FP is the main research policy instrument of the European Community. The FPs were introduced in the early 1980. They are agreed upon by the member states of the European Union (EU) and are implemented over the span of several years.[1] They function as an umbrella of specific programmes fund research across a variety of fields such as information and communications technologies, energy, biotechnology, health, advanced materials, and manufacturing. The supported RTD must have a European added value and the projects are almost exclusively undertaken by consortia of at least three partners representing a minimum of three member states of the EU or other affiliated countries.

The current Treaty of the EU identifies two core strategic objectives for the FP: (i) strengthening the scientific and technological bases of industry to encourage its international competitiveness and (ii) supporting other policies of the EU. The FP has undergone significant changes during the past decade and a half, reflecting developments in the socio-economic context of the region and the Community's realisation of the programmes' importance. FP3 (1990–1994) had the development of the Internal Market in the background, FP4 (1994–1998) had the Maastricht Treaty and the White Paper on Growth Competitiveness and Employment, FP5 (1998–2002) had the rising interest in socio-economic values and FP6 (2002–2006) has had the European Research Area (ERA) in the background. One feature has not changed in this process: successive FPs have tried to achieve their objectives by promoting collaborative research. This procedure put in place in the early 1980s when the FP was being established on the foundations of the industry roundtable organised in the early 1980s by Commissioner Davignon to assist the competitiveness of the European electronics industry.

Aiming at facilitating ERA, the FP6 has had an even stronger focus on research integration than any of its predecessors. The programme has introduced new funding instruments that combined with more traditional instruments to provide a multitude of opportunities for collaboration. The salient features of the FP instruments are as follows:[2]

- Integrated projects (IPs) are large projects with systemic work-plans that connect a large number of research, development and deployment activities. Overall workflow is fairly well laid out from the beginning. The coordinating organisation has a key role and mediates participation. IPs are likely to involve a wide range of organisations from the research and business communities. In some cases, work tends to be modular.
- Networks of excellence (NoEs) are large projects with much more internal flexibility to pursue 'portfolio' exploration from a range of alternatives. They are primarily intended to combine and cross-fertilise existing strands of research around a common core issue. They are more likely to involve publicly-supported research organisations and to have less centralised or hierarchical structures than IPs.
- Specific targeted research projects (STRePs) reflect smaller consortia and more narrowly focused research that is innovative within a predetermined work-plan. They are self-contained. They are the closest instrument to the typical collaborative research traditionally supported by the FPs.

- Coordinated actions (CAs) and specific support actions (SSAs) provide other forms of support or coordination to ongoing research efforts and areas of policy application in other instruments.
- Information society technologies (IST) has been a core priority of the FPs since the very start (Peterson and Sharp 1998; Caloghirou, Vonortas, and Ioannides 2004). This priority has been encapsulated in a host of well known earlier programmes such as ESPRIT I-IV, RACE I-II, ACTS, DELTA, DRIVE, TAP I-II and AIM. Such programmes and their derivatives were placed under the overall IST Thematic Priority in the Fifth Framework Programme (1998–2002) that continued in the Sixth (2002–2006), also including media applications of all kinds. IST has maintained a leading position in successive FPs as it is a core piece of the policy objective of the Community to establish a leading global knowledge economy (the so-called Lisbon strategy). The IST thematic priority has thus commanded a large share of the FP budget throughout the years, amounting to almost a quarter of overall funding in FP6. The Community has high expectations for the contribution of its IST investment to competitiveness, economic growth and employment as it is stressed in the renewed Lisbon Strategy and the Plan i2010.[3]

2.1. *Modern evaluation concepts and networks*

Public support for RTD has traditionally been justified in the economics literature on the basis of market failures. The market failure rationale is based on the difference between the benefits to society (social returns) and the benefits to the individual/organisations undertaking the RTD investment (private returns). The greater this difference is, the larger the spillovers from the private party to the rest of society and the lesser the willingness of the private party/sector to invest at the socially optimal level.

More recently, analysts have also identified system failures for government intervention. Supporting arguments reflect issues of path dependence, technological lock-in, investment timing (technology life cycles, trajectories), institutional constraints (general infrastructure), coordination failures (e.g. standards), and the ineffectiveness of mechanisms facilitating knowledge flows. More and beyond accounting for inputs and outputs/outcomes, the systems approach concentrates on the dynamics of RTD and innovation, i.e. the processes involved in generating innovation outcomes. A primary interest here is in an organisation's or a nation's capacity to innovate and in the mechanisms that allow it to take full advantage of its capabilities (Edquist 2004).

Such considerations have underlined the concept of *additionality*, which has proven useful as an organising devise when considering public support for RTD (Organisation for Economic Cooperation and Development (OECD) 2006):

- *Input additionality*. Has public expenditure created additional funds to be spent and on what?
- *Output/outcome additionality*. Has public expenditure generated additional private and social returns?
- *Behavioural additionality*. Has public expenditure created sustainable effects beyond the infusion of resources and outputs such as improving the knowledge, capabilities, organisations and strategies of firms?

It is the third aspect of additionality where the network approach can make its greatest contribution. By studying relationships, exchanges, network location and status, network structure and evolution through time, and participant characteristics and roles in the network, this approach provides a new prism to examine important aspects of the longer-lasting, more sustainable contributions of public policy in affecting organisational and national/regional capabilities to innovate. The results reported in this paper primarily relate to the third concept of (behavioural) additionality.

Two earlier studies made significant progress in mapping the IST research networks in Europe and in examining the topological features of such networks.[4] They found that the network of European IST-RTD research collaborations has:

- A 'scale-free architecture' at the thematic level, meaning a pattern of (preferential) attachment that underlines the extensive influence of relatively few 'hub' organisations and the relatively minor influence of a much larger number of peripheral organisations;
- 'Small world' connectivity, meaning efficient communications between local clusters that facilitate the dissemination of knowledge;[5]
- Closer, stronger, denser linkages among organisations with the introduction of IPs and NoEs in FP6, with large firms and research institutes taking on even more central network positions than in earlier FPs;
- Participants that are also likely to be part of other European networks such as COST (focusing on science) or EUREKA (focusing on technology application).

Our work complements the earlier studies and significantly expands the scope of using the network methodology for evaluation purposes by both examining in greater length the IST-RTD networks and by comparing them to the global networks. The analysis has addressed important phenomena such as the role of IST-RTD funding in creating and sustaining knowledge hubs, the relative stature of these hubs in the global IST network, the role of the new funding instruments (IPs and NoEs) in supporting and extending the network, and the inclusiveness of core national research organisations.

3. Methodology

3.1. *Network data*

We use large-scale quantitative data on the participation of European organisations in various knowledge-related collaboration activities. More specifically, the study examines three types of network relations, which are illustrated in Table 1.

The IST-RTD Network provides the core network. On the basis of available information, we built two networks for IST-RTD projects: the IST applications network that includes

Table 1. Types of examined networks.

Type of network	Description	Source
IST-RTD network	European network formed by organisations participating in FP6 IST TA1 and TA2/3 projects (partnership network)	Internal EC database (not publicly available)
Global network	Global network formed by companies involved in privately funded alliances (partnership network)	INNET dataset (George Washington University)
Knowledge network	Knowledge network arising from cross-organisational patent citations	EP-CESPRI dataset (European Patent Office)

projects in Thematic Area 1 (‘applied IST research addressing major societal and economic challenges’) and the IST development network that includes projects in Thematic Areas 2 and 3 (‘communication, computing and software technologies’ and ‘components and micro systems’).

The IST-RTD network (applications and development) is complemented by two broader networks within which knowledge and resources are exchanged and transferred: the global (partnership) network and the knowledge (patent) network. This way, the IST-RTD network is placed in the broader context of networks of knowledge relations spontaneously emerging from the initiatives of individual organisations.

The global network of strategic alliances enables one to assess the extent to which European organisations involved in the IST-RTD network are also involved in the broader global network of RTD collaborations in the relevant technological domains. More importantly, one can evaluate whether and to what extent IST-RTD projects have achieved the objective of nurturing global knowledge leaders, on the one hand, and supporting the creation of additional knowledge linkages over and above those autonomously forged by private companies, on the other. To this purpose, we have used the INNET database that reports information on worldwide strategic alliances. For this study we have selected only those strategic alliances whose technological content is related to the domains pertaining to IST-RTD projects in the examined thematic areas (see Appendix Table A1 for the list of standard industrial classification codes selected).

An important channel of knowledge transfer is represented by the disembodied flow of scientific and technological information (knowledge spillovers). Although capturing this type of knowledge flows in their totality is difficult, an approximation frequently used in the economic literature involves patent citations to prior art (e.g. Jaffe and Trajtenberg 2002). The fact that patent A cites patent B as prior art is perceived as an indication of some kind of knowledge flow from the organisations responsible for patent B to the organisations responsible for patent A. Moreover, the fact that patents of organisations B are frequently cited by patents of other organisations suggests that organisations B represent an important repository of knowledge and ideas for other organisations, i.e. it is a knowledge leader. Based on patent citations data, the analysis of the knowledge network in this study aimed therefore to assess to what extent European organisations involved in IST-RTD projects are effective knowledge leaders. To this purpose, we have used the EP-CESPRI dataset that provides information on patent applications to the European Patent Office. For this study we have collected all patent documents whose technological classification is related to the domains pertaining to IST-RTD projects in the examined thematic areas (see Appendix Table A2 for the list of International Patent Classification codes selected).

3.2. *Analytical methodology*

The analysis has been conducted at the level of individual organisations. Three basic types of organisations were considered: private companies (IND), higher education institutions (HE), and public research organisations (REC). The main analytical tool is graph theory and its applications, also known as social network analysis (Wasserman and Faust 1994). A network may be defined as a set of actors (or nodes) linked by some kind of relational tie. A network thus defined may be visually depicted as a sociogram in which nodes are represented as points in two-dimensional space and relationships among pairs of actors are represented by lines (edges) linking the corresponding points.

In this paper, nodes are organisations while relational ties are of three different kinds:

(1) organisations *a* and *b* are linked by an edge if they have been partners in at least one IST-RTD project (IST applications network and IST development network)
(2) organisations *a* and *b* are linked by an edge if they have been partners in at least one strategic alliance (global network)
(3) organisations *a* and *b* are linked by an edge if organisation *a*'s patents are cited (or have been cited by) organisation *b*'s patents (knowledge network)

To keep the analysis as simple as possible, we have used only undirected and binary valued networks. This means that we disregard both the direction and the intensity of the ties linking pairs of organisations. The sociogram represented in Figure 1 illustrates a hypothetical network, where nodes represent organisations and edges may be thought of as capturing any of the relational ties just described.

Table 2 provides a few summary statistics concerning the size of the four networks examined, in terms of number of organisations involved, number of links and size of the largest component (i.e. the largest connected subgraph in terms of number of nodes). We note that the largest component fills a very large proportion of the graph, thus indicating that the vast majority of organisations involved in EU sponsored programmes are, directly or indirectly, connected to each other via collaboration.

A core concern of the paper is to examine the position occupied by different organisations in the various types of networks and, more specifically, to understand how the position of European organisations involved in the network represented by IST-RTD funded projects maps onto their position within the broader set of knowledge relations.

Although there are different ways to characterise the position of a node in a network, a very important dimension of it relates to the notion of *Network Hub*. Informally, a hub may be defined as a node with a large number of connections or, alternatively, as a node that is highly influential by playing the role of network *connector*, i.e. one connecting nodes that would otherwise remain

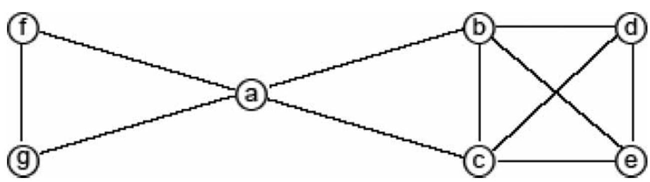

Figure 1. Example of sociogram.

Table 2. Descriptive statistics of examined networks.

	IST-RTD partnership network			
	IST application network (TA1)	IST development network (TA2/3)	Global partnership network	Knowledge network
Number of organizations	1660	1112	14,943	17,849
Number of links	32,398	23,340	18,531	78,629
Giant component	1625 (94.09%)	1094 (98.38%)	7297 (48.82%)	17,387 (87.26%)

unconnected. Hubs have therefore an extremely important role in partnership and knowledge networks as they contribute towards the effective and fast diffusion of knowledge even to the most peripheral nodes of the network.

More formally, the notion of network hub may be captured by two indicators: degree centrality and betweenness centrality. Degree centrality is simply defined as the number of lines incident with a node. In the context of this study, degree centrality is defined as the number of other organisations with which the focal organisations has a relational tie.[6] Betweenness centrality is a measure of the influence a node has over the spread of information and knowledge through the network. The basic idea is that a node, which lies on the information path linking two other nodes, is able to exercise a control over the flow of knowledge within the network. Formally, it is defined as the fraction of shortest paths (i.e. the minimum number of lines connecting two nodes) between node pairs that pass through the node of interest.[7]

Degree centrality and betweenness centrality have been calculated for all organisations and a synthetic index has been composed by the joint rankings of organisations in terms of these two indicators. *Hubs* have been defined as the top 2% of the organisations on the basis of the joint ranking.[8]

This procedure has been separately applied for each type of relational tie. It defines three types of hub, each corresponding to one of the three kinds of networks considered herein (the most important hubs are listed in the Appendix Tables A3 and A4):

(1) IST-RTD hubs (33 hubs for the IST applications network and 23 hubs for the IST development network)
(2) Global hubs (300 hubs for the global network)
(3) Knowledge hubs (374 hubs for the knowledge network)

The notion of 'hub' applies to single networks. Once one considers multiple networks in which an organisation is embedded at the same time – for example the IST-RTD network and the global IST network – the relevant concept is that of *Gatekeeper*, defined to be an organisation that plays the role of hub in more than one network.

Our study was mainly directed to the assessment of the existing relations among the different participants and only partially investigated the effective exchange through the observed links. We made some efforts to overcome this limitation. First, in Section 4.4, we use patent data to give a measure of knowledge exchanges effectiveness between partners. We have also followed and other strategy. We have 'complemented' the results of empirical analysis with qualitative information. We have interviewed some European experts, stakeholders and some qualified members of the organisations participating in the projects. This has been done in two ways, during two workshops organised by the EU and through a series of individual extensive interviews.[9]

4. Findings

The analysis presented herein concentrated on the identification of those organisations participating in the IST-RTD projects that are playing the role of hubs within the FP network and the comparison of their positioning with that within the broader global networks in IST. In short, how much overlap is there between FP IST network hubs and global IST network hubs? What may be the role of such hubs in the European research systems? Furthermore, what may be the role of the new funding instruments of FP6 – IPs and NoEs – in facilitating the effectiveness of such hubs?

To what extent are IST-RTD collaboration networks inclusive of national research networks and key large and small IST enterprises around Europe?

4.1. *Various types of organisations play the role of hubs in IST-RTD networks*

An objective of FP6 has been to encourage networking among different types of organisations, including industry, higher education institutions and research centres. Given the absence of quantitative targets, one can consider that the objective has been achieved if the shares of these different types of organisations are somewhat balanced in terms of their participation and in terms of the role they play in the network. To address this issue we have identified the top organisations playing the role of hubs in the IST applications and IST development networks.

Table 3 reports the distribution of hubs by organisational type for the IST applications network and the IST development network[10] and compares the distribution with the participation rates in the IST-RTD projects. In both networks, one finds a rather even distribution of hubs among firms, higher education institutions and public research organisations. Universities play a disproportionate role as hubs compared with their participation rates in the IST applications network. Public research organisations are far more represented as hubs compared to their weight in terms of participation in the IST development network.[11]

The different funding instruments affect the type of hubs in the network. If the linkages formed by NoEs are excluded, the role of industrial organisations as hubs increases: they account for 55% of all hubs in the IST applications network and around 45% of all hubs in the IST development network. This reflects the fact that NoEs host a larger proportion of participants from higher education institutions and public research organisations. Moreover, it reflects the propensity of different organisations to take a leading role in projects that differ across instruments: industrial actors tend to assume coordinating roles relatively more frequently in projects funded by instruments such as IPs and STRePs, while leaving that task primarily to HE and REC in NoEs.

4.2. *Important global hubs actively engage in the IST-RTD networks*

An important concern is the extent to which IST projects have been able to attract the major actors in the global network of RTD collaborations in information and communication technologies (ICT) and, therefore, have managed to activate direct and indirect links with the major global network players. Figure 2 shows the geographical distribution of hubs in the global network. Few of them are European. Even discounting the US dominance, few European organisations are able to occupy core positions in the global ICT alliance networks.

Table 3. Hubs in IST-RTD networks.

	IST applications network		IST development network	
	Participants (%)	Hubs (%)	Participants(%)	Hubs (%)
Higher education	25.5	39.2	32.7	29.0
Industry	35.1	37.3	39.0	34.4
Research centre	14.4	23.5	10.9	36.6
Others	25.0	0	17.4	0
Total (%)	100	100	100	100
Total (abs. value)	1660	33	1112	23

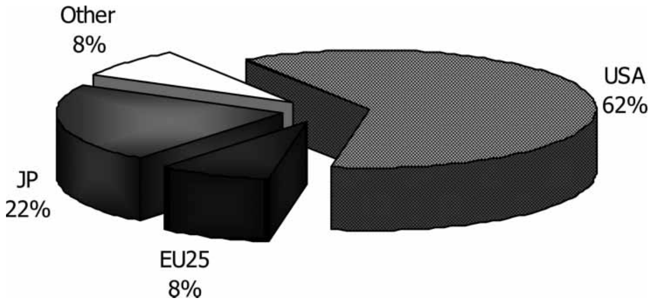

Figure 2. Distribution of top 100 global hubs by area.

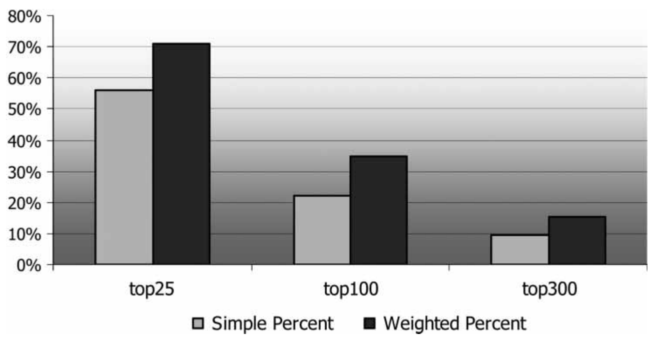

Figure 3. Percent of global hubs participating in IST projects.

IST projects are able to attract global hubs. Figure 3 shows that more than half of the top 25 global hubs participate in the examined IST-RTD projects. This share rises to around 70% if companies are weighted by their ranking, meaning that the relatively most influential companies in the global network also participate in the IST-RTD projects. A comparison with the top 100 and 300 global hubs shows that the share participating in IST-RTD projects is lower than for the top 25 shown here, but the weighted share (according to the ranking of hubs) is always higher.

More important, some of the global players attracted to the IST thematic priority serve as gatekeepers, i.e. they have a dual role of in the global hub and the hub in the IST-RTD network. These organisations link organisations involved in IST-RTD with the broader global network of RTD collaboration. Their position in both networks puts them at the crossroads of information and knowledge flowing within IST-RTD projects and information and knowledge flowing within the much broader global network of strategic alliances.

This is illustrated by Figures 4 and 5, which report a subset of the IST applications and the IST development networks respectively. The partition contains only organisations (nodes) that are hubs in these two networks and the ties among them. IST-RTD hubs have been assigned different shades and shapes according to the organisational type and to their also being global hubs. The organisations' names are reported only for the first seven organisations according to the ranking based on centrality indexes.

The graphs show that a few industrial actors play the dual role of IST-RTD hub and global hub at the same time (gatekeeper). This occurs both in both the IST applications network and the IST development network.

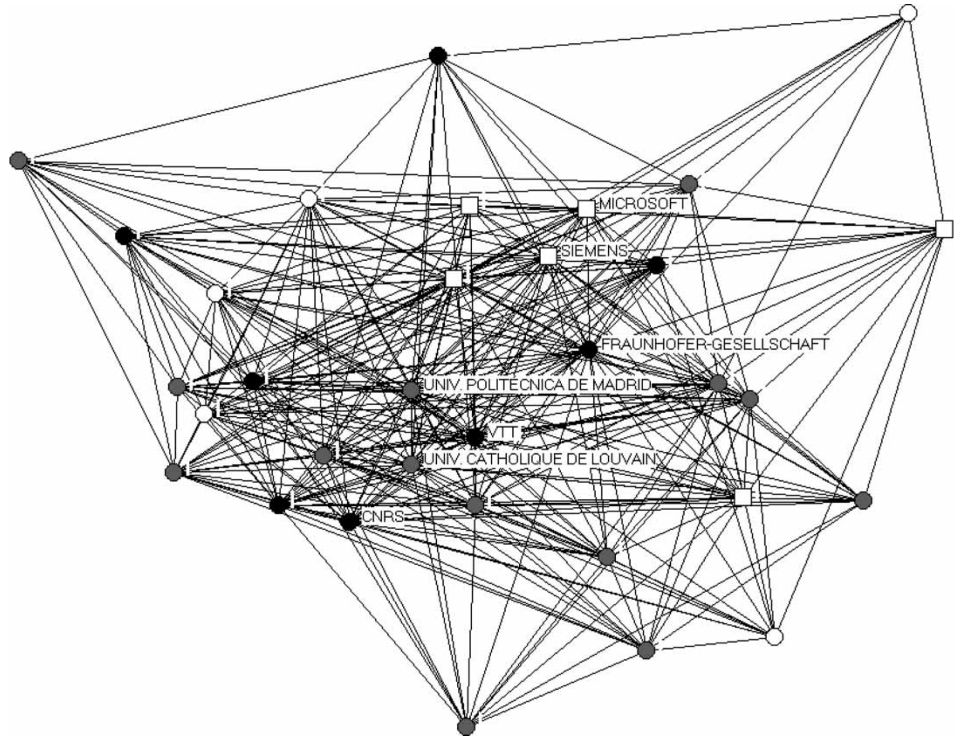

Figure 4. IST applications hubs. Key: white = industry, grey = university, black = public research centre; ◯ = IST-RTD hub, □ = gatekeeper (IST-RTD and global hub).

4.3. *Effectiveness in connecting IST-RTD organisations and global hubs*

Figures 6 and 7 report the fraction of all linkages between pairs of actors accounted for by the three major funding instruments of FPs (i.e. IPs, NoEs and STRePs), respectively for the IST applications network and the IST development network. IPs and NoEs account for the bulk of linkages and STRePs account for the bulk of projects. STRePs, in particular, account for half of all projects but for just 10% of the links.

In order to examine the effectiveness of the various funding instruments in linking IST project participants to global hubs, we have focused on the linkages among the various types of hubs and among them and other non-hub organisations. More specifically, the following groups of actors have been considered: IST-RTD hub, global hub, gatekeeper and other IST-RTD organisations. In terms of instruments, we consider IPs, NoEs and STRePs.

Results are reported in Figures 8 and 9 for the IST applications and the IST development networks respectively. The figures show the relative importance of an instrument in linking groups of actors pairwise. The relative importance is defined in terms of the ratio of the percentage share of links between two specific groups of actors depending exclusively on an instrument and the percentage share of links among any organisation that depend on that instrument. A ratio higher than one means that the instrument in question is relatively important in bridging the two specific groups. For example, in the IST applications network, IPs play a relative important role in bridging IST-RTD hubs and global hubs (but which are not hubs in the IST applications network) because the

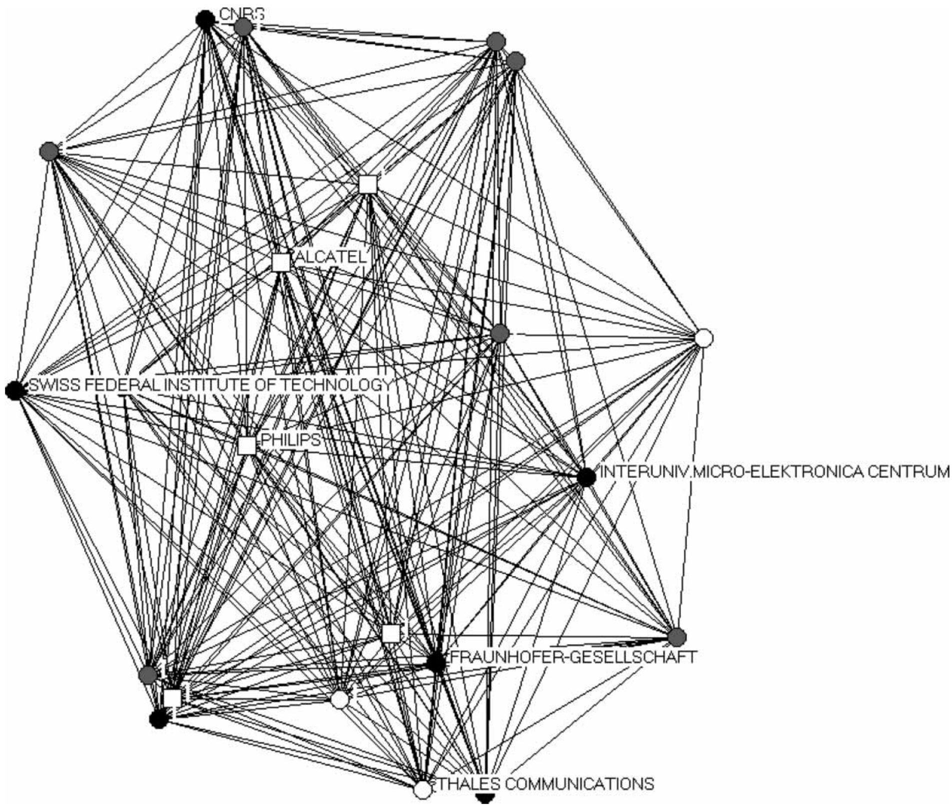

Figure 5. IST development hubs. Key: white = industry; grey = university; black = public research centre; ◯ = IST-RTD hub; □ = gatekeeper (IST-RTD and global hub).

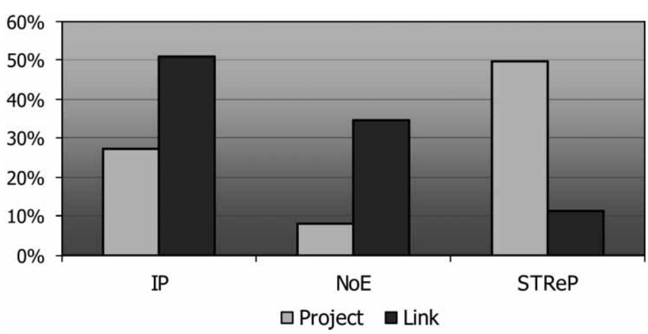

Figure 6. IST applications network percent of projects and links depending on three instruments.

share of links between these groups of organisations depending exclusively on IPs is significantly higher than the average share of links depending exclusively on IPs. In the figure, only instruments playing a relative important role in bridging two groups of actors are reported.

The results are striking and provide strong support to the idea that IPs are highly effective instruments for connecting IST-RTD hubs and global hubs and for connecting global hubs (gatekeepers

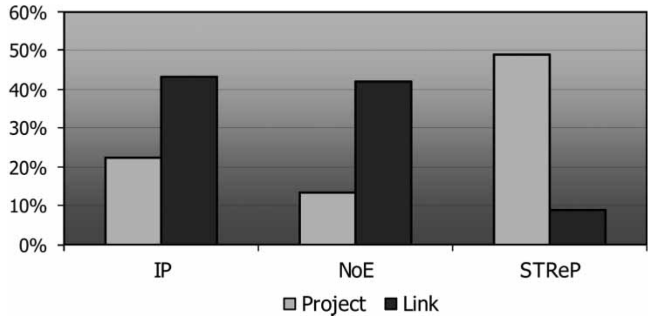

Figure 7. IST development.

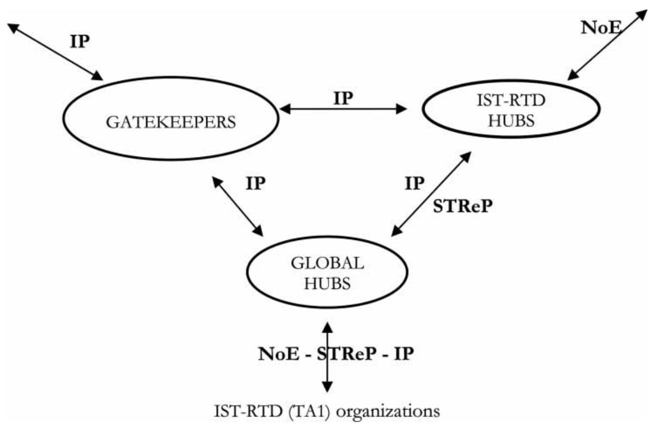

Figure 8. Relative importance of IPs, NoEs and STRePs in bridging IST applications network organisations network. Percent of projects and links depending on three instruments.

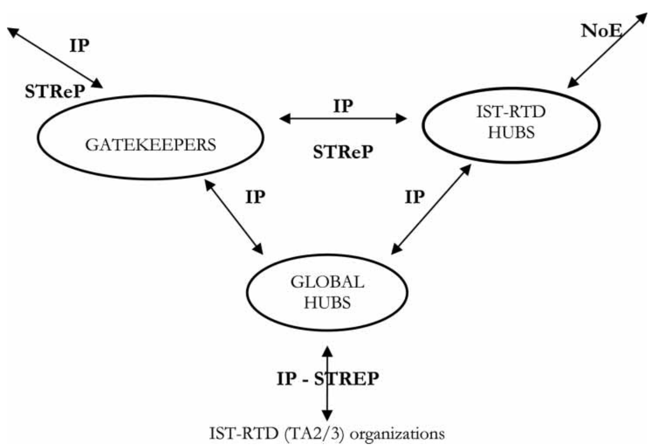

Figure 9. Relative importance of IPs, NoEs and STRePs in bridging IST development organisations.

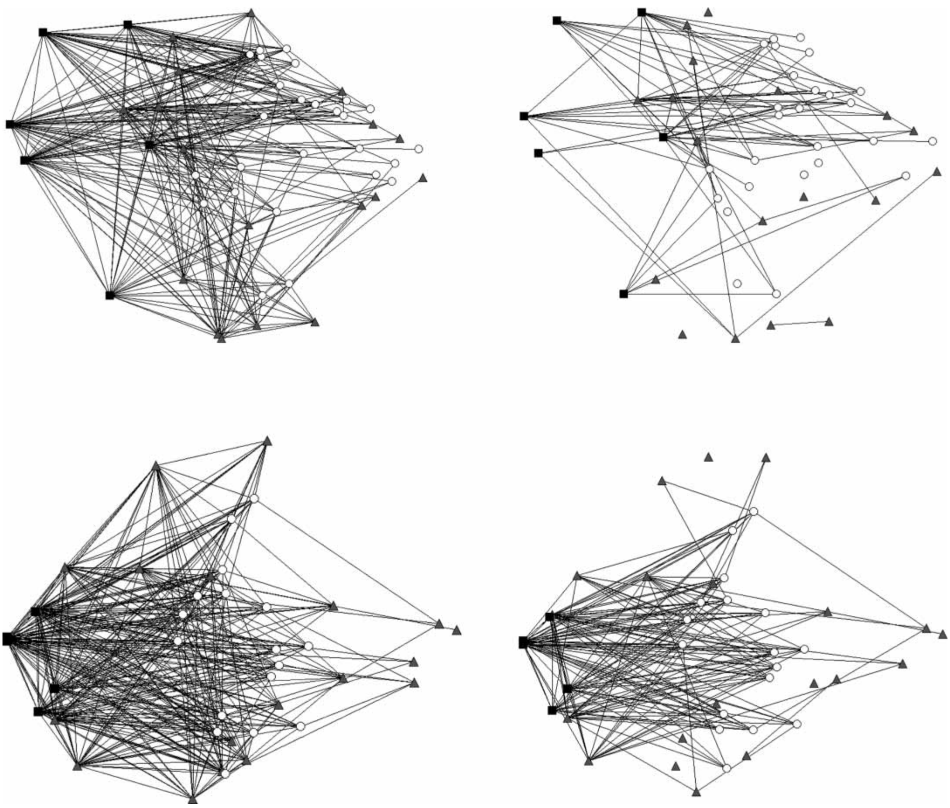

Figure 10. Linkages among hubs in the IST-RTD networks with IPs (left panel) and without IPs (right panel). Key: ◯ = IST-RTD hubs only, ■ = gatekeepers, ▲ = global hubs only.

or not) to other organisations. NoEs seem to be relatively less effective in this specific role; they are more relevant in linking IST-RTD hubs to other organisations. STRePs are effective in linking global hubs to other organisations in both the examined networks.

Another way to test the importance of IPs in connecting organisations is by taking a subset of the IST-RTD networks containing only hubs (both IST-RTD and global hubs) and investigating how many linkages among them would be severed without the IPs. This is shown in Figure 10.

The graphs illustrate that the elimination of the linkages attributable to IP projects has a major impact on overall connectivity, especially in relation to the IST applications network. Several hubs become isolates while degree centrality is substantially reduced for others. In sum, IPs can be considered as an effective instrument connecting directly global hubs to IST-RTD hubs and, largely through them, to many other IST organisations.

For companies, NoEs seem less effective than IPs in connecting global hubs and IST-RTD hubs. One reason is that NoEs are more effective in connecting higher education organisations to each other and to public research organisations (REC) than to other kinds of organisations.

The apparent effectiveness of IPs for putting together heterogeneous actors with different and complementary competences can be considered a strength of this instrument in terms of promoting the ERA objectives. IPs seem to create the scale and ambition necessary to develop technology platforms, thus, propelling some European hubs to positions of global stature. Because they are large and ambitious, IPs also tend to attract global hubs that provide connectivity to the world leaders.

Our interviews with European experts in the IST field highlighted (CESPRI 2006, 91ff.) the fact that IPs are characterised by the participation of larger organisations that are more diversified, have more diffuse research capabilities and broader market reach. Their ability to include the smaller, gazelle-type of companies and in what capacity, was questioned. The role of the prime contractor was reportedly critical in IPs. Experience in coordinating large projects becomes paramount for success and, it was argued, should be one of the criteria in picking IP projects. This, in turn, gives these organisations significant bargaining power.

Universities and research centres were considered to play an important role in IP networks because they focused on more long-term and fundamental parts of the research. The promotion of more intensive knowledge transfer between university and industry was assessed by the experts an area where the FP could contribute significantly. This means greater mobility of people, increased opportunities where the two meet, more funding for the maintenance of the research infrastructure and improvement of channels for technology take-up and exploitation.

As for the other funding instruments, STReP projects were considered highly effective in achieving their technical goals by the interviewed experts because they are narrowly focused and are easier to coordinate. On the contrary, as previously shown, NoEs are dominated by high education and research organisations and they tend to be very large and diffuse. Industry has been hesitant to participate because NoEs are perceived to have difficulty with research quality control, they do not necessarily involve all excellent partners and they are often too big (creating problems for coordination and knowledge diffusion and sharing).

4.4. *Hubs' effectiveness at producing and diffusing knowledge*

Section 4.1 identified hub organisations in the IST partnership networks, including both the FP-IST context (IST-RTD hubs) and the global IST context (global hubs). In both these networks, organisations align in order to get access to the knowledge assets of partners, diversify risk and complement resources regarding important RTD projects and more generally network with others considered important in specific fields. The implication is that an organisation will not be asked to participate if it does not have something useful to offer in terms of intellectual capital, especially in the case of prime contractors in FP networks and core organisations in partnership networks.

One may expect a high degree of correlation between partnership hubs and knowledge hubs in their respective contexts. The interviews with experts from industry and from public research centres made clear that a prerequisite for assuming a core position in a partnership network like those analysed herein is the 'respect' an organisations commands among its peers, suppliers and buyers for its capabilities. Larger organisations with widespread resources and capabilities, especially intellectual capital, that span several fields are prime candidates.

In this context, the paper has examined the inventive record of each partnership hub and its role in diffusing and exchanging knowledge as a reasonable proxy for the evaluation of its effectiveness. We have adopted the following definition: '*An effective knowledge Hub operates as a knowledge depository and/or is a recognized source of information and ideas.*' Effectiveness, in this sense, reflects the contribution of an organisation in enriching the knowledge network with new knowledge, on one hand, and in facilitating the dissemination of knowledge among network members, on the other.

We have used the EP-CESPRI patent database to measure inventive activity and to derive indicators of knowledge diffusion and human capital mobility. For that purpose we have used all patent applications to the European Patent Office in the ICT-related fields. In this sense, the coverage of the patent database is global.

Three indicators have been used to capture the effectiveness of organisations in producing new knowledge:

(1) *Number of patents*: number of patent applications filed from 1996 to 2002 in the relevant technological fields.
(2) *Number of citations received*: number of citations received by the patents of an organisation weighed by (divided by) the total number of patents of that organisation. It is a measure of quality of the patent portfolio of an organisation.[12]
(3) *Number of highly cited patents*: number of frequently cited patents. It is a measure of importance of the patent portfolio of an organisation.

As argued earlier, an important channel of knowledge transfer is represented by the disembodied flow of scientific and technical information, i.e. knowledge spillovers. Information contained in patent citation patterns can be used to assess the effectiveness of an organisation in disseminating knowledge. Specifically, patent citations have been used to build up the knowledge network in which nodes are patenting organisations and ties are patent citation relationships among them. On this basis, for each organisation we have calculated two indicators:

(1) *Degree centrality* in the knowledge network: number of direct connections of an organisation (nodes). Nodes with highest degree are the most active in the sense that they have the most ties to other actors in the network graph.
(2) *Betweenness centrality* in the knowledge network: an actor is central if it lies between many pairs of other actors not directly connected between them. A node with high betweenness centrality has great influence over knowledge flows in the network.

Results show that IST-RTD hubs[13] are more inventive and more central than other IST-RTD participants, thus being quite effective in both the generation of new knowledge and diffusion of existing knowledge (Figure 11, top panel). IST-RTD hubs are also more effective in the generation and diffusion of knowledge and inventiveness than global hubs (Figure 11, bottom panel). In addition:

- The global hubs that participate in IST-RTD are more effective in every respect than those global hubs that do not participate. The FP attracts global hubs that are relatively more effective in terms of both producing and diffusing information.
- Global hubs that are also IST-RTD hubs (i.e. gatekeeper organisations) are relatively more effective than those global hubs that just participate in IST-RTD but play no major role in it.
- Gatekeepers compare favourably to organisations that are only IST-RTD hubs.

The analysis so far has considered all kinds of organisations that serve as hubs: industry, universities and public research centres. However, given that not all types of organisations emphasise patenting equally, one would worry about bias in measures of effectiveness based on inventive activity to the extent that different groupings – say, IST-RTD hubs and other IST-RTD participants – host significantly different proportions of non-patenting organisations. We have checked the sensitivity of the results reported above when considering only firms. Results (not reported here) turned out to be robust.

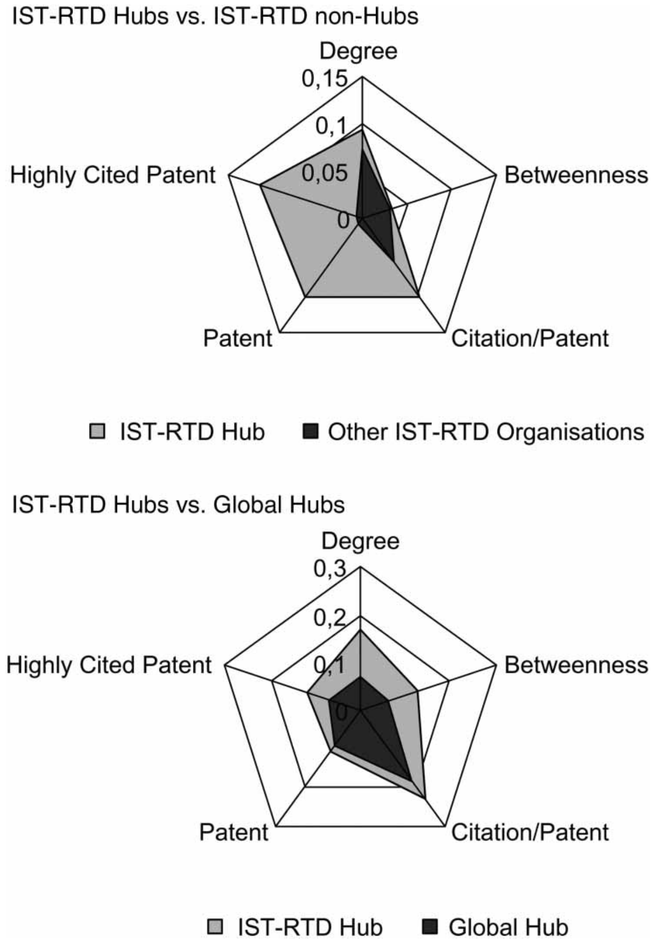

Figure 11. Effectiveness in producing and diffusing knowledge.

The importance of hubs is related to the scale-free nature of the examined networks (see Section 2.2). Scale-free nature implies that a relatively small number of hubs – that is, organisations that are most highly sought after by others – offer important benefits to partners in terms of knowledge assets and network resources. Hubs are viewed by others as high-status partners either because they are perceived as depositories of knowledge and/or because they are situated in privileged sections of the network facilitating flows of information and ideas. Larger organisations with widespread resources and capabilities, especially intellectual capital, that span several fields are prime candidates.

According to the interviewed experts from industry and from leading research centres engaged in the IST field, this reflects a set of key hub characteristics. One is research excellence and the sustenance of strong areas of in-house expertise. Another is strong technological capability, including the maintenance of multi-talented teams and expertise across several areas. A third is organisational, related to the ability to manage effectively sets of alliances involving different partners. Then there is global reach – or European reach if we are referring to a European network – in terms of alliances, markets and organisations. Last, but not least, are market exploitation capabilities in terms of holding strong market positions that makes partnering desirable to others.

4.5. *Small world and scale-free emerging properties*

The final empirical observations to report here are that the network emerging from IST-RTD projects has both the characteristics of a small world and a scale-free network[14] (see also Breschi and Cusmano 2004). On the one hand, the property of small world refers to the fact that the average distance among the participating organisations in the IST-RTD network is relatively low and, at the same time, each organisation is embedded in a tightly connected (local) cluster. This structure is believed to be effective both for the creation (high cliquishness) and the dissemination (low distance) of knowledge, especially when complex and difficult to absorb knowledge is at stake (Verspagen 2006; Watts 1999). On the other hand, the IST-RTD network also has the property of a scale-free network, which is typical of large emergent networks. This means that the network contains a minority of highly interconnected hubs and a large majority of nodes are weakly connected. The IST-RTD network hubs are highly connected to other organisations as well as to each other.

The emergence of a small-world topology in the IST-RTD network may be interpreted as the (unintended) consequence of the rules governing the participation in IST-RTD projects as well as of the initial conditions of the industry, which have favoured the formation and consolidation of a few ‘supernodes’. In particular, high transaction costs in FPs combined with the typical relative scarcity of resources in smaller firms have been major factors limiting such players from taking a coordinating role in IST projects. The most feasible way for getting access to IST funding for these companies is often through joining projects led by larger and more reputed organisations in the industry. The goal of achieving long-run cohesion and diffusion of knowledge in this field seems, then, to have been achieved indirectly by focusing on funding a restricted set of network participants and relying upon their coordination capabilities to attract more and more peripheral organisations. The network that has emerged from IST-RTD projects can thus be depicted to have a two-layer structure, where a very large number of organisations (non-hubs), frequently of smaller size, float around and are highly dependent upon small group of core and highly interconnected organisations (hubs).

This structure provides an important input in efforts to streamline funding instruments in order to increase the effectiveness of the IST-RTD network. The instruments used so far have been successful at creating a network structure that is effective in producing and disseminating knowledge at the RTD level by strengthening links among hubs while also favouring the formation of links between hub organisations and non-hub organisations, therefore pulling in the network more peripheral actors. However, a few potential risks should be also noted. In particular, as long as participation and funding of IST-RTD projects remain conditioned on the access to a few anchor companies and institutions, it is unlikely that organisations that join the network late will ever become hubs. Moreover, to the extent that research priorities and network organisations are defined by core participants, the risk of lock-ins and the resistance to re-orient the network towards more productive research areas increase accordingly. The policy implication would be that, besides funding instruments aimed at further increasing linkages among hubs (e.g. IPs) and among hubs and non-hubs organisations (e.g. NoEs), emphasis should be placed towards more flexible and manageable instruments that allow smaller organisations to take a leading and coordinating role in IST projects. If one of the objectives of EU IST policies is to nurture the development of new European hubs, policies and instruments better tailored to the needs and constraints of non-hub organisations should be promoted.

5. Conclusions and policy implications

The European Research Framework programmes create emergent social networks through the voluntary participation of organisations and individuals in the funding competitions. These emergent networks include links with varied history: the observed link could build on extant formal relations between the affected organisations, or extend an existing partnership, or may be the starting point of a formal collaboration. By extension, the FPs for RTD create networks characterised by a wide discrepancy in the criticality of different nodes (organisations, individuals) for the network. Few nodes appear to be placed in more critical positions in the network than the large majority of other nodes. More central network positioning generates visibility and reputation, facilitates timely access to resources and information and, thereby, also ensures higher leverage and control. This, in turn, raises the status of these nodes and makes them especially desirable as partners. Such nodes possess atypical bargaining power in the network: they become brokers and shapers of events.

The implication for policy is straightforward: core organisations may provide the critical policy lever in the effort to achieve objectives and approach optimal solutions. Such organisations could play a pivotal role in steering the network toward desired socio-economic situations. For the FP, these situations translate into a strengthened scientific and technological base, enhanced international competitiveness of industry, and appropriate support for other policies of the EU.

In this study we have applied social network analysis to a set of specific programmes of the Sixth Framework Programme (2002–2006) in a two-year time window. We used social network analysis with the help of large datasets to assess the nature and relative network positioning of core European organisations identified as ‘knowledge hubs’. Hubs were defined to be organisations with a large number of connections and/or organisations that are highly influential by playing the role of connectors of parts of the network that would otherwise remain unconnected.

The most important outcome of the study is the confirmation that social network analysis is an empirical tool amenable to application in appraising the effectiveness of publicly funded RTD programmes. It is especially well suited to answer questions of ‘behavioural additionality’ that have hitherto been addressed only qualitatively.

Regarding the specific example of IST-RTD programmes appraised in the paper, network analysis showed the following:

- *IST-RTD programmes attract key actors to the European IST knowledge network*. IST-RTD projects are able to attract global hubs whether these hubs are based in Europe or not. The examined IST-RTD thematic area programmes tend to include a good share of the top knowledge hubs of most of the EU15 Member States. There is a rather even distribution of hubs among firms, higher education institutions and public research organisations in the examined IST-RTD programmes. The role of firms as hubs in IST-RTD networks increases significantly when NoEs are excluded.
- *IST-RTD programmes create and strengthen the connectivity among actors*. IST-RTD programmes create linkage additionality. IST-RTD projects add new and complementary links to existing linkages. IST-RTD programmes incorporate key organisations that are both IST-RTD hubs and global hubs. Mostly private sector companies, these organisations play a critical role as gatekeepers, effectively putting in contact organisations involved in IST-RTD with the broader global network of collaboration in information and communication technologies. Gatekeeper organisations are at the crossroads of information and knowledge flowing both within IST-RTD projects and within strategic alliances around the world. Integrated projects play a

critical role in connecting IST-RTD participants to the rest of the world. IPs are responsible for a very large fraction of ties in the IST applications network and the IST development network. Moreover, IP linkages account for a major part of overall connectivity among hubs. IPs are found to be an effective instrument in terms of connecting global hubs to IST-RTD hubs and, through them, connecting many other IST-RTD participants to the broader global IST network. For companies, NoEs seem less effective in that particular role.
- *IST-RTD programmes generate and diffuse new knowledge effectively*. Hubs are effective in producing and diffusing knowledge. Gatekeeper organisations – simultaneously global hubs and IST-RTD hubs – are the most effective in terms of both enriching the network with new knowledge and facilitating the dissemination of knowledge among network members. In turn, IST-RTD hubs are more effective than other IST-RTD participants in terms of both producing and disseminating new knowledge.

Corroborating the above is the final observation from our empirical analysis that the FP IST-RTD network is characterised by relatively tight connections between the participating organisations and by well-connected clusters (small world). This structure is believed by network theorists to be effective both for the creation and the dissemination of knowledge, especially when complex and difficult-to-absorb knowledge is at stake.

Finally, the scale-free property of the network – the network blends highly interconnected hubs with a large majority of relatively weakly connected organisations – points out the criticality, in the current structure of the network, of certain organisations for both the creation and dissemination of knowledge. To the extent that one of the objectives of EU IST funding is to nurture the development of new European hubs, instruments better tailored to the needs and constraints of non-hub organisations should be promoted. This could mean emphasis on more flexible and manageable instruments that allow non-core (often smaller) organisations to take a leading and coordinating role in IST projects.

We end with suggestions for future research. We invoked in the introduction the concept of behavioural additionality, referring to the contribution of the FP IST programmes in terms of changing actor behaviour and improving knowledge, capabilities, organisations and strategies of participants more and beyond what would have been the case in the absence of the programmes. While this concept was ever present in our paper through the use of different datasets of partnerships, those with and others without public funding, and through the comparisons between organisations and between networks, we did not perform behavioural additionality tests in the strict sense of the term. This was partly due to the lack of necessary information (for instance, no possibility of a survey). It was also partly due to the experimental nature of our analysis. We believe that there is significant room for adding analytical rigor in future appraisals of publicly supported networks in the sphere of additionality.

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Notes

1. The Seventh Framework Programme will run for seven years instead, 2007–2013.
2. In addition to the instruments listed below, the Commission has introduced in the past few years two other that are quite new and jointly with the FP projects aim at structuring and shaping the ERA, namely the ERANets and the Joint Technology Initiatives (JTIs). The ERANets scheme is about a bottom-up, self-organised coordination and cooperation of national and regional programmes. JTIs have the specific role to implement the research programme of a European Technology Platform (ETP). ETPs help industrial and academic research communities and other stakeholders in specific technology fields to coordinate their research and to tailor it to a common strategic research agenda, which sets out research and development goals, time frames and action plans for technological advances that are relevant to industry and society. Both these instruments are characterised by a bottom-up approach, thus being complementary to more traditional FP funding instruments where the priorities are defined by the commission with a top-down approach. ERANets and JTIs were not part of this research.
3. European Commission (2005a,b).
4. J. Stefan Institute (1999) and RAND Europe (2005).
5. This result and the previous one are not surprising since other studies analysing FP networks have reached similar conclusions, e.g. Breschi and Cusmano (2004).
6. With reference to the hypothetical sociogram depicted in Figure 1, nodes a, b and c present the highest values of degree centrality being connected to four other organisations.
7. With reference to the hypothetical sociogram (Figure 1), it is intuitive that node a has a high influence as a network connector. For example, the shortest path between organisations d and g has length 3 and organisations a lies on it. If one takes all possible pairs of organisations (excluding a) and counts the number of shortest paths connecting them, it turns out that organisations a lies on 8 out of 15 of them. The betweenness centrality of organisations a is therefore equal to $8/15 = 0.53$. It is therefore highly influential in mediating knowledge flows taking place among the nodes in the network. By contrast, organisations b lies only on three shortest paths (connecting node d with a, f and g) and is thus characterised by a lower value of betweenness centrality (0.20).
8. 'If you go for the biggest nodes and take a couple of them out, you can break the system into clusters that don't communicate with each other' (Albert, Jeong, and Barabasi 2000, 381) This idea developed by Barabasi and co-authors in several studies has been applied in the context of this study. It is enough to focus on the size of the greatest subpart

of a network: the so-called giant component (i.e. the greatest set of actors directly or indirectly connected). As one starts deleting the top ranked organisations in terms of centrality as well as their links, the size of the giant component as a percentage of nodes included in it drops dramatically. In the case of the global network, deleting the top 2% of hubs reduces the giant component to one third of its initial size. The 2% cut-off is obviously arbitrary. However, we also considered different values (both higher and lower then 2%) to check for robustness.

9. The participants in the two workshop were EU officers of different DGs of the Europe Commission (Research, Information Society and Media, etc.), delegates of National or Regional organisations, academic experts and members of organisations participating in the IST projects. We ran also about 10 interviews with representatives of project participants. Only main organisations, both public and private, have been selected. See CESPRI (2006, 91) onwards, for questions and (aggregated) answers.
10. The percentage values for each type of organisation have been weighted according to the ranking in the overall list of hubs. The rationale for using weighted percentages is that organisations ranking high in the list of hubs are likely to be relatively more influential than organisations ranking low. The weights have been defined in the following way: $w_i = (\max r + 1 - r_i)/\Sigma r_i$, where r_i is the ranking of organisation i and $\max r$ is the maximum value of the ranking. Please note that the weights sum to 1.
11. Firms participating in IST projects have been consolidated according to the ultimate parent company. For example, Nokia Italy has been considered as part of the Nokia group. The research labs of large public research organisations (e.g. Fraunhofer Gesellschaft) have been also consolidated. As a robustness check, we have recalculated the list of hubs by considering each subsidiary or research lab as an independent unit. Results are not significantly sensitive to the consolidation of companies and research laboratories.
12. Company self citations have been excluded.
13. In this section, IST applications and IST development hubs are examined jointly.
14. For the empirical analysis leading to these observations see the original report ‘Evaluation of Progress towards a European Research Area for Information Society Technologies’, European Commission, DG Information Society and Media (2006), by the authors of this paper.

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Appendix

Table A1. The selected 4-digit standard industrial classification codes.

SIC code	Description
3651	Household audio and video equipment
3661	Telephone apparatus
3663	Radio & telephone
3571	Electronic computer
3572	Computer storage
3575	Computer terminals
3674	Semiconductors
3286	Laboratory instruments
3287	Optical instruments
7371	Computer programming services
7372	Prepackaged software
7373	Computer integrated systems design
7375	Information retrieval services

Table A2. The selected international patent classification codes.

Technology field	IPC codes
Audiovisual technology	G09F, G; G11B; H03F, G, J; H04N, R, S
Telecommunications	G08C; H01P, Q; H03B, C, D, H, K, L, M; H04B, H, J, K, L, M, Q
Information technology	G06; G11C; G10L
Semiconductors	H01L
Optics	G02; G03B, C, D, F, G, H; H01S
Control technology	G01B, C, D, F, G, H, J, K, L, M, N, P, R, S, V, W; G04; G05B, D; G07; G08B, G; G09B, C, D; G12
Medical technology	A61B, C, D, F, G, H, J, L, M, N

Table A3. IST applications network hubs.

Rank	Organisation	Organisation type
1	Fraunhofer-Gesellschaft	REC
2	**Siemens AG**	IND
3	Université Catholique de Louvain	HE
4	Universidad Politécnica de Madrid	HE
5	VTT Technical Research Centre of Finland	REC
6	Centre National de la Recherche Scientifique	REC
7	**Microsoft**	IND
8	Swiss Federal Institute of Technology	HE
9	Fiat	IND
10	**Hewlett-Packard**	IND
11	Ecole Polytechnique Federale de Lausanne	HE
12	**Nokia**	IND
13	Centre for Research and Technology – Hellas	REC
14	University of Southampton	HE
15	Aristotle University of Thessaloniki	HE
16	**IBM**	IND
17	Universitat Politècnica de Catalunya	HE
18	Schlumberger	IND
19	Kungl Tekniska Högskolan (Royal Institute of Technology)	HE
20	Thales Communications	IND
21	Institute of Communication and Computer Systems	REC
22	**Motorola**	IND
23	Universität Duisburg–Essen	HE
24	Vodafone	IND
25	Daimlerchrysler AG	IND
26	The University of Surrey	HE
27	Università degli Studi di Siena	HE
28	Vienna University of Technology	HE
29	Università degli Studi di Roma ‘La Sapienza’	HE
30	Institut National de Recherche en Informatique et en Automatique	REC
31	Deutsches Forschungszentrum für künstliche Intelligenz GmbH (German Research Centre for Artificial Intelligence)	REC
32	Technical University of Crete	HE
33	Foundation for Research and Technology – Hellas	REC

Organizations in bold are also hubs in the global network (i.e. gatekeepers).

Table A4. IST development network hubs.

Rank	Organisation	Organisation type
1	Fraunhofer-Gesellschaft	REC
2	Interuniversitair Micro-Elektronica Centrum VZW	REC
3	Centre National de la Recherche Scientifique	REC
4	Thales Communications	IND
5	Swiss Federal Institute of Technology	HE
6	**Philips**	IND
7	**Alcatel**	IND
8	**Telefónica Investigación y Desarrollo Sociedad Anónima Unipersonal**	IND
9	Universitat Politècnica de Catalunya	HE
10	Budapest University of Technology and Economics	HE
11	VTT Technical Research Centre of Finland	REC
12	Institut National de Recherche en Informatique et en Automatique	REC
13	France Telecom	IND
14	Institute of Communication and Computer Systems	REC
15	Universidad Politécnica de Madrid	HE
16	**Siemens AG**	IND
17	Ecole Polytechnique Fédérale de Lausanne	HE
18	Université Catholique de Louvain	HE
19	The University of Surrey	HE
20	**Motorola**	IND
21	Chalmers University of Technology	HE
22	Kungl Tekniska Högskolan (Royal Institute of Technology)	HE
23	ST Microelectronics	IND

Organizations in bold are also hubs in the global network (i.e. gatekeepers).