Networked Research:
European Policy Intervention in ICTs*

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Abstract: 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 organizations that can be characterized 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.

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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 emphasized 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 organizations involved (behavioural additionality). This paper focuses on the latter.

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 et al, 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, realized through the partnership and knowledge networks that such investments create.

We have utilized 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 utilized 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: How are Hubs positioned in networks created through IST-RTD funding? How does it compare to their positioning within the broader global networks in IST? 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? 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 organizations that can be characterized 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 summarizes key features of the Framework Programme 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 organizations. Finally, Section 5 summarizes the results and offers policy implications.

2. THE FRAMEWORK PROGRAMME AS A NETWORKING ENVIRONMENT

The Framework Programme (FP) is the main research policy instrument of the European Community. The Framework Programmes were introduced in the early 1980. They are agreed upon by the member states of the European Union 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 European Union or other affiliated countries.

The current Treaty of the European Union 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 European Union. 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 realization 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

[1] The Seventh Framework Programme will run for seven years instead, 2007-2013.

established on the foundations of the industry roundtable organized 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 which combined with more traditional instruments to provide a multitude of opportunities for collaboration. The salient features of the FP instruments are as follows:

- Integrated Projects (IPs) are large projects with systemic workplans 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 Framework Programmes since the very start (Peterson and Sharp, 1998; Caloghirou et al, 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 (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.[2]

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/organization 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 organizing devise when considering public support for RTD:

- *Input additionality*: Has public expenditure created additional funds to be spent and on what?

[2] European Commission, 2005 and 2005a.

- *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, organization 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.[3] 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" organizations and the relatively minor influence of a much larger number of peripheral organizations;
- "Small world" connectivity, meaning efficient communications between local clusters which facilitate the dissemination of knowledge;[4]
- Closer, stronger, denser linkages among organizations with the introduction of Integrated Projects and Networks of Excellence in FP6, with large firms and research institutes taking on even more central network positions than in earlier Framework Programmes;
- Participants which are also likely to be part of other European networks such as COST (focusing on science) or EUREKA (focusing on technology application).

[3] J. Stefan Institute 1999 and RAND Europe 2005.

[4] This result and the previous one are not surprising since other studies analysing Framework Programme networks have reached similar conclusions, e.g. Breschi and Cusmano 2004.

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 (Integrated Projects and Networks of Excellence) in supporting and extending the network, and the inclusiveness of core national research organizations.

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.

[Table 1 about here)

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 which includes projects in Thematic Area 1 ("Applied IST Research Addressing Major Societal and Economic Challenges") and the IST Development Network which 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 allows 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, it permits to 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 which 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).

On the other hand, 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 organisation responsible of patent B to the organisation responsible of patent A. Moreover, the fact that organisation B's patents are frequently cited by patents of other organisations suggests that organisation B represents 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 which 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:

- 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)
- organisations *a* and *b* are linked by an edge if they have been partners in at least one strategic alliance (Global Network)
- organisations *a* and *b* are linked by an edge if organisation *a*'s patents 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.

[Figure 1 about here)

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.

[Table 2 about here)

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 characterize 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 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 betwenness 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 organisation has a relational tie.[5] Betweenness centrality, on the other hand, 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 frac-

[5] 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.

tion of shortest paths (i.e. the minimum number of lines connecting two nodes) between node pairs that pass through the node of interest.[6]

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.[7]

This procedure has been separately applied for each type of relational tie. It defines three types of Hubs, 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):

- IST-RTD Hubs (33 Hubs for the IST Applications Network and 23 Hubs for the IST Development Network)
- Global Hubs (300 Hubs for the Global Network)
- 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 which plays the role of Hub in more than one network.

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[6] 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 organisation *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 organisation *a* lies on 8 out of 15 of them. The betweenness centrality of organisation *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, organisation *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).

[7] "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 et al., 2000, p. 381) This idea developed by Barabasi and coauthors 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 percentage of nodes included in it drops dramatically. In the case of the Global Network, deleting the top 2 percent of Hubs reduces the giant component to one third of its initial size. The two per cent cut-off is obviously arbitrary. However, we also considered different values (both higher and lower then two per cent) to check for robustness.

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 exchange effectiveness between partners. We have also followed another strategy. We have 'complemented' the results of the empirical network 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 at the European Union and through a series of individual extensive interviews.[8]

4. FINDINGS

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 [9] and compares the distribution with the participation rates in the IST-RTD projects. In both networks, one finds a rather even distribu-

[8] The participants in the two workshops were officers from different DGs of the European Commission (Research, Information Society and Media, etc), delegates of National or Regional organizations, academic experts and members of organistions participating in the IST projects. We ran also about ten interviews with representatives of project participants. Only principle organizations, both public and private, have been selected. See CESPRI 2006a, p. 91 onwards, for interview questions and (aggregated) answers.

[9] 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.

tion of Hubs among firms, higher education institutions and public research organizations. Universities play a disproportionate role as Hubs compared to 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.[10]

[Table 3 about here)

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 which differs 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.

[Figure 2 about here)

[10] 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.

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.

[Figure 3 about here)

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 organizations 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 colours 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.

[Figures 4 and 5 about here)

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.

4.3. Effectiveness in connecting IST-RTD organizations 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 Framework Programmes (i.e. Integrated Projects (IPs), Networks of Excellence (NoEs) and Specific Targeted Research Projects (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 percent of the links.

[Figures 6 and 7 about here)

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* organisations 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) since the 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.

[Figures 8 and 9 about here)

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 or not) to other organisations. On the other hand, 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.

[Figure 10 about here)

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 organizations 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 which provide connectivity to the world leaders.

Our interviews with European experts in the IST field (CESPRI, 2006a) highlighted the fact that IPs are characterized by the participation of larger organizations which 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 organizations significant bargaining power.

Universities and research centres were considered to play an important role in IP networks because they focussed 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 focussed and are easier to coordinate. On the contrary, as previously shown, NoEs are dominated by High Education and Research Organizations 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 organizations 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 organisation commands among its peers, suppliers and buyers for its capabilities. Larger organizations 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 organization 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:

- *Number of Patents*: number of patent applications filed from 1996 to 2002 in the relevant technological fields.

- *Number of Citations Received*: number of citations received by the patents of an organization weighed by (divided by) the total number of patents of that organization. It is a measure of quality of the patent portfolio of an organisation.[11]
- *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:

- *Degree Centrality* in the knowledge network: number of direct connections of an organization (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.
- *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[12] 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:

[11] Company self citations have been excluded.
[12] In this section, IST Applications and IST Development Hubs are examined jointly.

- 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 which just participate in IST-RTD but play no major role in it.
- Gatekeepers compare favourably to organizations that are only IST-RTD Hubs.

[Figure 11 about here)

The analysis so far has considered all kinds of organizations that serve as Hubs: industry, universities and public research centres. However, given that not all types of organisations emphasize 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.

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, organizations 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 organizations 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 organizational, 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 organization. Last, but not least, are market exploitation capabilities in terms of holding strong market positions that makes partnering desirable to others.

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. By extension, the Framework Programmes for RTD create networks characterized 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 Framework Programme, these situations translate into a strengthened scientific and technological base, enhanced international competitiveness of industry, and appropriate support for other policies of the European Union.

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 organizations with a large number of connections and/or organizations 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" which 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 Networks of Excellence (NoE) 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 collaborations 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 (IPs) play a critical role in connecting IST-RTD participants to the rest of the world. Integrated Projects 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.

A final observation relates to the result that the network emerging from IST-RTD projects has the characteristics of being at the same time a *small world* and a *scale-free* network. 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. On the other hand, the IST-RTD network also has the property of being a scale-free network, implying that it contains relatively few highly interconnected Hubs while the vast majority of nodes are weakly connected. The IST-RTD network Hubs are not only highly connected to other organisations, but are also highly interconnected 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 Framework Programmes 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 small organisations (non-Hubs) 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 which 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 organisation 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.

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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)

Table 2. Descriptive Statistics of Examined Networks

	IST-RTD Partnership Network		Global Partnership Network	Knowledge Network
	IST Application Network (TA1)	IST Development Network (TA2/3)		
Number of Organisations	1660	1112	14943	17849
Number of Links	32398	23340	18531	78629
Giant Component	1625 (94.09%)	1094 (98.38%)	7297 (48.82%)	17387 (87,26%)

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 1. Example of Sociogram

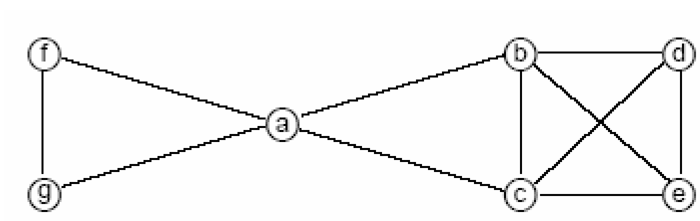


Figure 2. Distribution of Top 100 Global Hubs by area

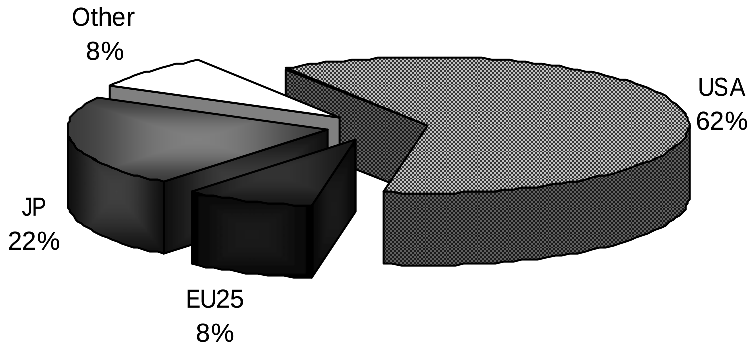


Figure 3. Percent of Global Hubs participating in IST projects

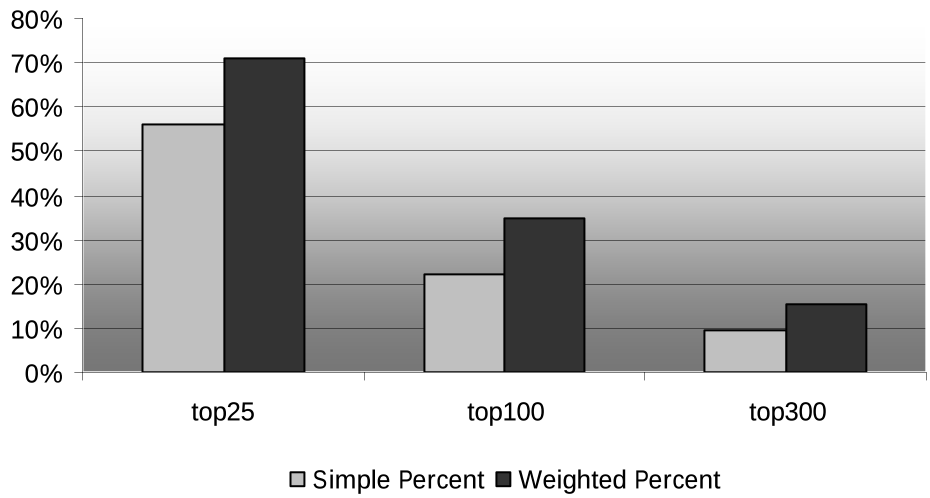


Figure 4 IST Applications Hubs
(white=industry, grey=university, black=public research centre)
(○=IST-RTD Hub, □=Gatekeeper (IST-RTD *and* Global Hub))

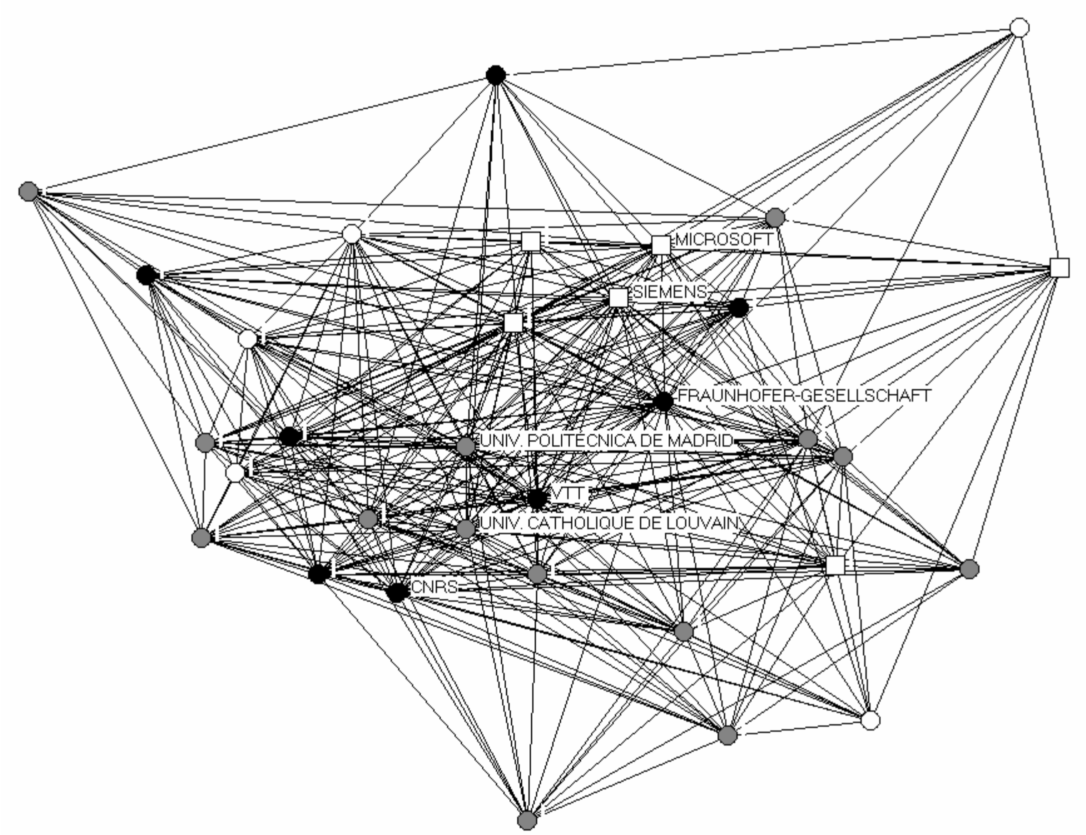


Figure 5. IST Development Hubs
(white=industry, grey=university, black=public research centre)
(○=IST-RTD Hub, □=Gatekeeper (IST-RTD *and* Global Hub))

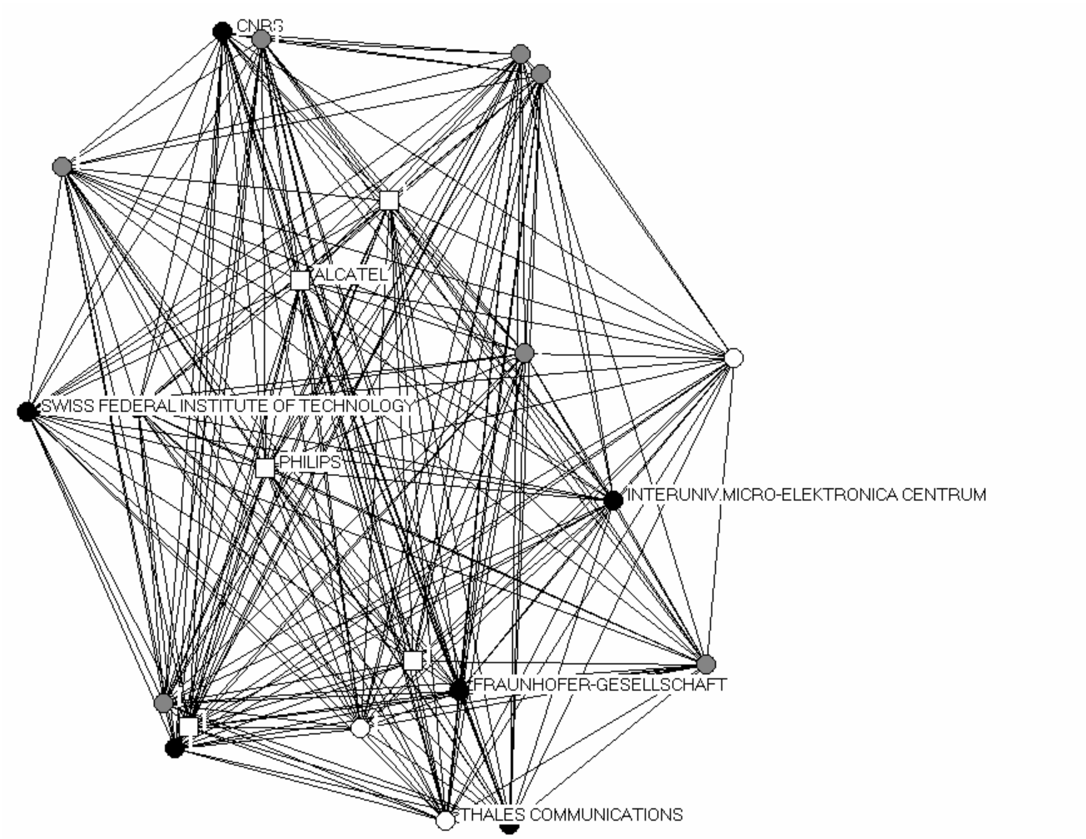


Figure 6. IST Applications Network
percent of projects and links depending on three instruments

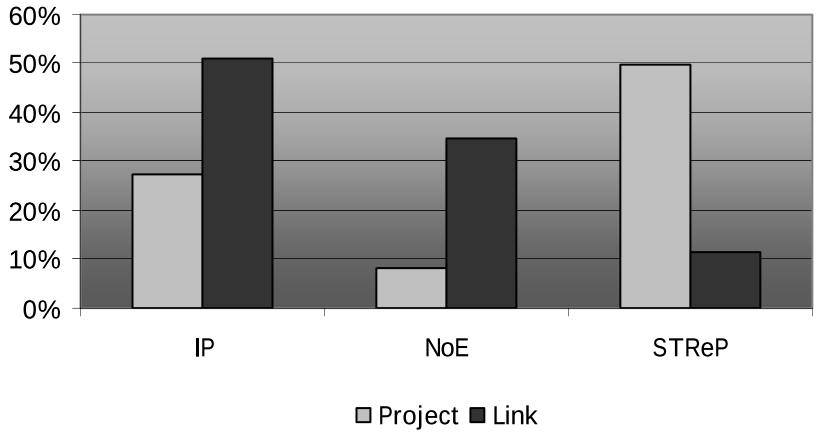


Figure 7. IST Development Network
percent of projects and links depending on three instruments

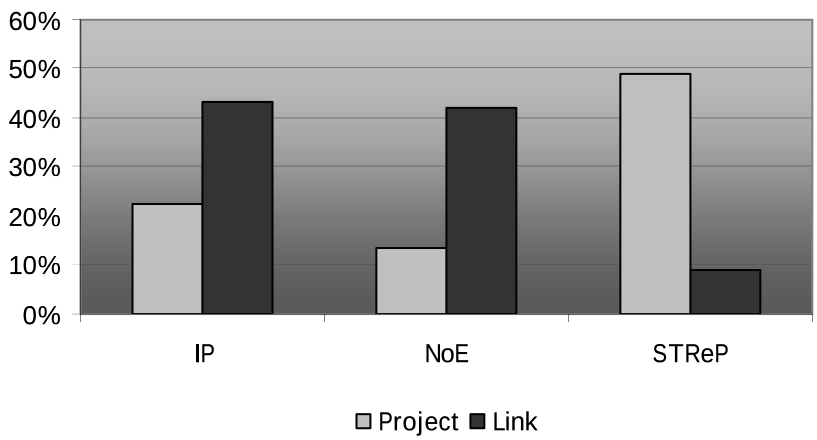


Figure 8. Relative importance of IPs, NoEs and STRePs in bridging IST Applications Network Organisations

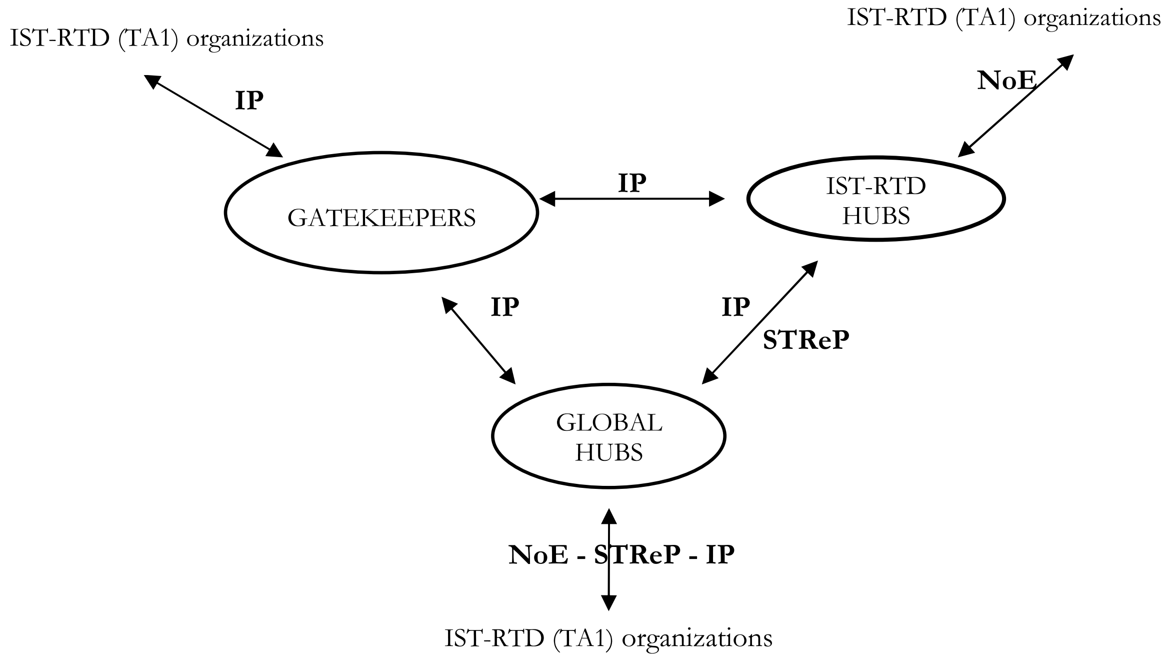


Figure 9. Relative importance of IPs, NoEs and STRePs in bridging IST Development Organisations

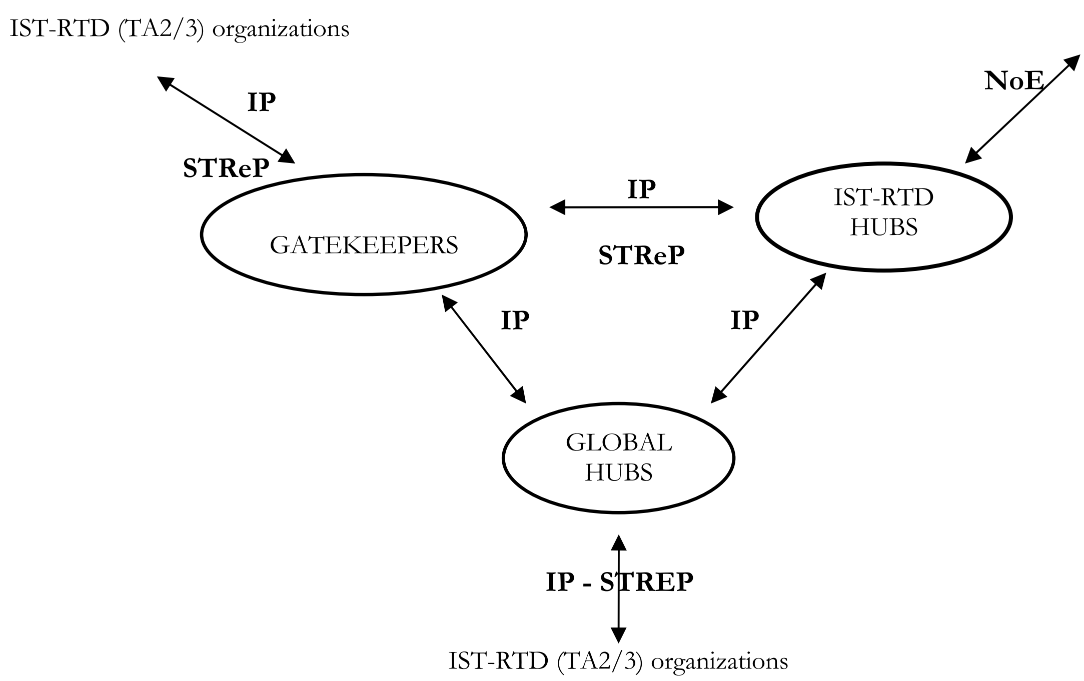
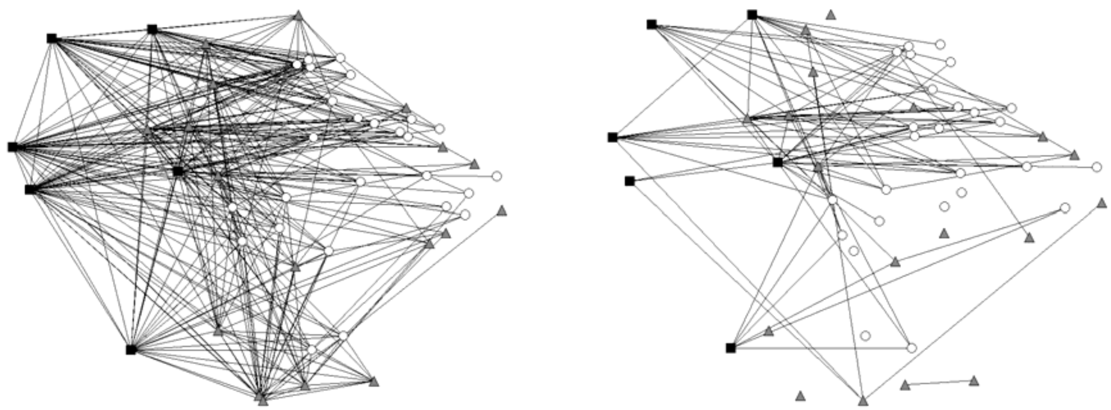


Figure 10. Linkages among Hubs in the IST-RTD Networks
with IPs (left panel) and without IPs (right panel)
[○=IST-RTD Hubs only, ■ = Gatekeepers, ▲= Global Hubs only]

IST Applications Network



IST Development Network

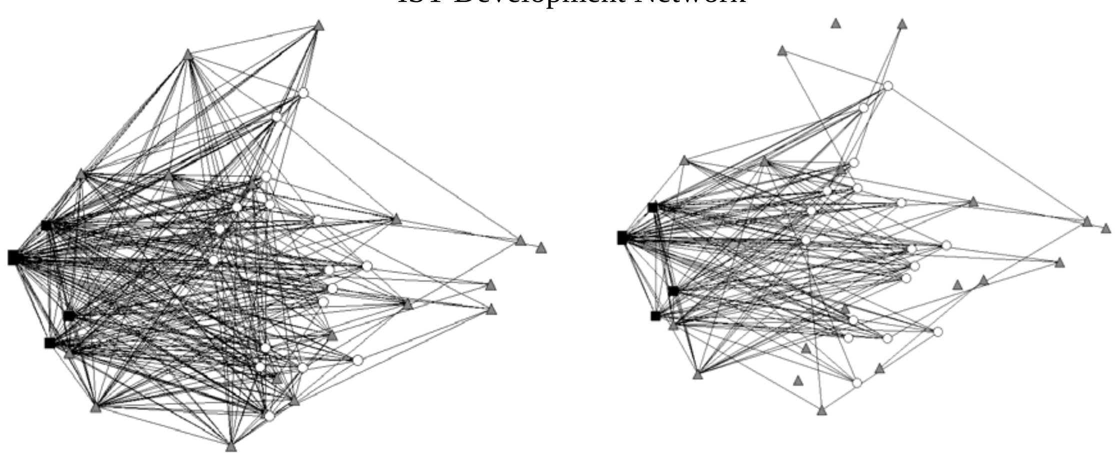
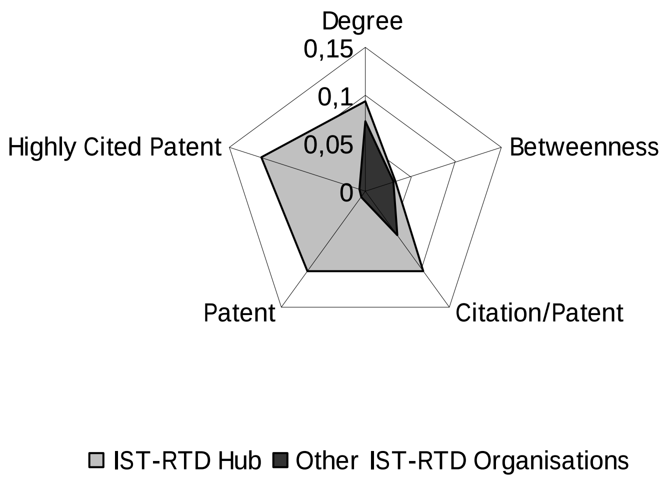
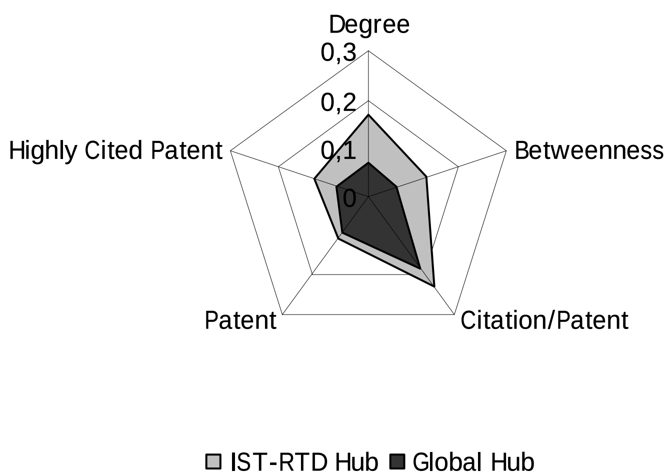


Figure 11. Effectiveness in producing and diffusing knowledge

IST-RTD Hubs vs. IST-RTD non-Hubs



IST-RTD Hubs vs. Global Hubs



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 FÉDÉRALE 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 CENTER FOR ARTIFICIAL INTELLIGENCE)	REC
32	TECHNICAL UNIVERSITY OF CRETE	HE
33	FOUNDATION FOR RESEARCH AND TECHNOLOGY - HELLAS	REC

Organisations 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	STMICROELECTRONICS	IND

Organisations in bold are also Hubs in the Global Network (i.e. Gatekeepers).