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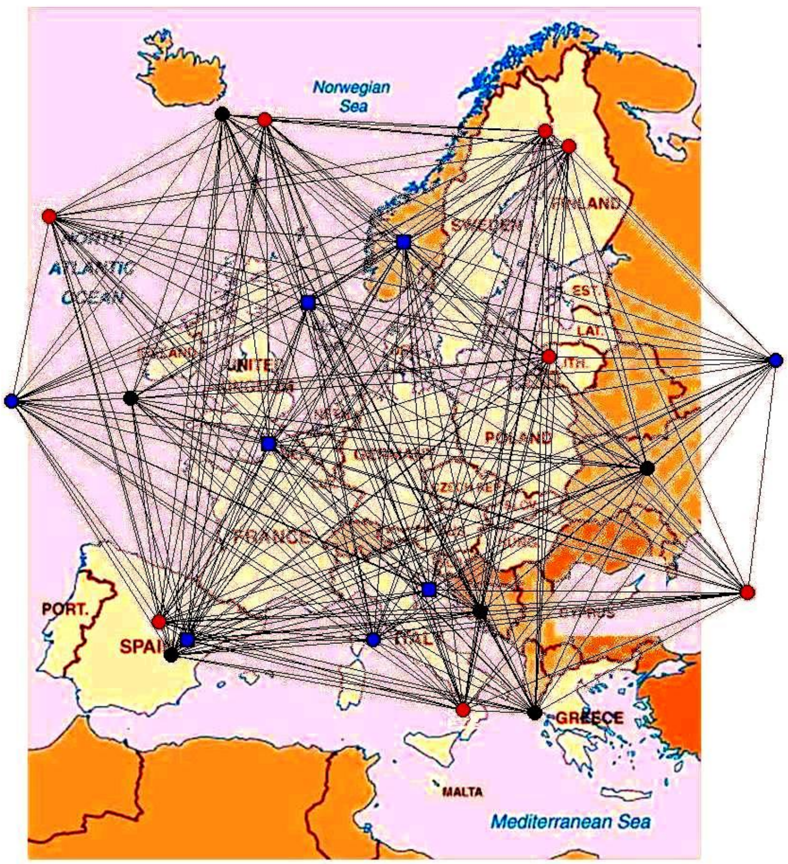

Evaluation of progress towards a *European Research Area* for Information Society Technologies

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Preface

This report presents the main results of a study, ***Evaluation of progress towards a European Research Area for Information Society Technologies***, conducted for the European Commission by the *Centre for Research on Innovation and Internationalization* (CESPRI) of Università Commerciale Luigi Bocconi, Milan. The study purported to appraise aspects of the research networks created through the funding by the Information Society and Technology (IST) Priority of the Community's Research Framework Programme. The evaluation primarily concentrated on three Thematic Areas featured in the first two IST Calls (2002-2004) of the Sixth Framework Programme (FP6).

The evaluation developed and applied a quantitative methodological framework for high-quality, comparative assessment of inter-organizational networks established by IST-RTD programmes and global networks developing independently of Community funding. In addition, qualitative information obtained through a series of expert/practitioner interviews was utilized to calibrate some of the results and obtain stakeholder suggestions for the future.

The study was conducted between January and December 2005 under the direction of Peter Johnston, Head of Unit, and Frank Cunningham, Evaluation Specialist, Evaluation and Monitoring Unit of the Information Society and Media Directorate Generale, European Commission. A steering committee of experts guided the project, including: Mark Buchanan, Author; Bart Verspagen, Eindhoven University of Technology; Caroline Wagner, RAND Europe and George Washington University.

The project team included the following CESPRI affiliates: Franco Malerba (Director), Nicholas Vonortas (CESPRI and George Washington University), Stefano Breschi (Deputy Director), Lorenzo Cassi, Federico Ferrario, Luca Todesco and Silvia Di Battista.

During the course of the study, the project team received very valuable and helpful comments and suggestions on work-in-progress at three Workshops held in Brussels. The National Contact Points in Member States were also requested to provide some key information. Our analysis greatly benefited from these interactions.

Methodological issues and preliminary results were presented at the *Annual meetings of the American Evaluation Association* (AEA) organized together with the *Canadian Evaluation Society* (CES) in Toronto (October 2005) and at the *Annual meetings of the Association for Public Policy Analysis and Management* (APPAM) in Washington DC (November 2005).

This report reflects the results of research and analysis conducted by CESPRI. The results do not necessarily reflect the view of the European Commission, of the Steering Committee or any of the experts consulted during the course of the project. Comments on this Report can be sent to Lorenzo Cassi, CESPRI, Università Bocconi, Milano, via Sarfatti 25, 20136 Milan, Italy; lorenzo.cassi@unibocconi.it

Executive Summary

This report evaluates the partnership and knowledge networks created locally and globally in relation to the Information Society Research and Technological Development (IST-RTD) Programmes of the Sixth Research Framework Programme (FP6). It argues that IST-RTD Programmes have a positive role in attracting key actors, in creating and increasing network connectivity, and in generating and diffusing new knowledge. It also 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.

Europe has achieved significant benefits from its sizeable investments in information society technologies (IST), many of which have been captured in the periodic evaluation exercises such as the latest 5-year Assessment of the Programme. The Community maintains high expectations for the contribution of its IST investments to competitiveness, economic growth and employment as it is stressed in the renewed Lisbon Strategy and the plan i2010.

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 created (output/outcome additionality). Such appraisals have, however, tended to miss the sustainable effects beyond the infusion of resources and/or the extraction of outputs that such investments create, such as improving the competencies, capabilities, organisational structures and strategies of firms (behavioural additionality). This report 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, a network serves as a locus for innovation 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.

This study has utilized social network analysis to assess several aspects of behavioural additionality in specific IST-RTD Programmes. It has investigated whether Calls 1 and 2 for 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") of FP6 have been successful in supporting effective Network Hubs that nurture global knowledge leadership and European cohesion. Hubs were defined in this study as organisations with many linkages and the ability to connect disparate parts of the network. In RTD Networks, such 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.

The study has differentiated between IST-RTD Network Hubs – organisations that are Hubs in the examined Programme networks – and Global Hubs – organisations that are Hubs in the international networks). These are our Knowledge Hubs.

Main Findings

The evaluation analysis reveals that the examined IST-RTD Programmes have very positive effects for the network connectivity of the European information and communication sector.

- ***Attracting key actors to the European IST Knowledge Network***

IST-RTD Programmes attract Global Hubs. IST-RTD Programmes are able to attract Global Hubs whether these Hubs are based in Europe or not. More than half of the top 25 Global Hubs participate in the examined IST-RTD Programmes. This share rises to about three quarters of the Global Hubs if organisations are weighted by their network ranking.

IST-RTD Programmes tend to attract the Hubs of Member States. The examined IST-RTD Thematic Area programmes tend to include a large fraction of the top organizations of most of the EU15 Member States. Probably due to their recent entry, the programmes include fewer such organisations from new Member States.

Different types of organisations play the role of Network Hubs in IST-RTD Programmes. Hubs are more or less evenly distributed among firms, higher education institutions, and public research centres in the examined IST-RTD Programmes. Universities, however, are overrepresented as Hubs compared to their weight in terms of participation in the IST Applications Network (i.e. IST-RTD Thematic Area 1). The same is true for public research organisations in the IST Development Network (i.e. IST-RTD Thematic Areas 2 and 3).

The importance of different types of organisations as Hubs differs across Instruments. The role of firms as Hubs in IST-RTD Networks increases significantly when Networks of Excellence (NoE) are excluded from the analysis. More than a half of the Hubs in the IST Applications Network and nearly one half in the IST Development Network are, then, accounted for by private sector companies.

- ***Creating and strengthening 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, organisations that are Hubs in both the IST-RTD and the global networks play a critical role as *gatekeepers*, effectively connecting participants 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 Programmes and within strategic alliances around the world.

Integrated Projects (IPs) connect IST-RTD participants to the rest of the world. Integrated Projects are responsible for a very large fraction of ties in the IST Applications and the IST Development Networks. 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, Networks of Excellence (NoEs) seem less effective than IPs in that particular role.

- ***Generating and diffusing new knowledge effectively***

Hubs are effective in producing and diffusing knowledge. Gatekeeper organisations – simultaneously Global Hubs and IST-RTD Hubs - are the most effective organisations in terms of enriching the network with new knowledge and facilitating the dissemination of knowledge among network members. IST-RTD Hubs are more effective than other IST-RTD participants in terms of both producing and disseminating new knowledge. In addition, IST-RTD Hubs contribute to the dissemination of knowledge by playing a key role in the mobility of inventors among European IST organisations.

* * *

The evaluation analysis has also identified two other features of the European information and communication technology industry and of the IST-RTD programmes that merit consideration.

- ***Few European organisations are top-rated Hubs in the Global IST Network***

Relatively few European companies can be characterised as Hubs in the Global IST Network. A small percentage of the top-rated Global IST Network Hubs have been identified as organisations headquartered in Europe.

- ***Few of the most technologically dynamic small and medium sized enterprises (SMEs) are part of the IST-RTD Programmes***

There is room for more extensive involvement of innovative SMEs in IST-RTD Programmes. While the examined Programmes include technologically active and innovative SMEs, they miss a large share of the most technologically dynamic such firms. SMEs do not, and probably cannot, play central roles in the resulting networks and therefore are not Hubs.

Policy Recommendations

The results of this study highlight the importance of Hubs in providing the underlying linkage infrastructure that maintains vibrant IST network communities that effectively produce and diffuse knowledge. The study also highlights some of the basic characteristics of these Hubs vis-a-vis other organisations in the IST network. Several policy recommendations are in order.

- *Promote the IST-RTD activities in the Research Framework Programme in order to maintain the connectivity and resilience of the European IST Network.*

The examined IST-RTD Thematic Area Programmes effectively contribute to attracting key actors in the European IST Network, creating and strengthening network connectivity, and nurturing the generation and diffusion of IST knowledge. For these reasons, IST RTD should remain a core part of the European Framework Programme.

- *Encourage the participation of Global Hubs and, more generally, expand the global reach of European IST-RTD Networks*

IST-RTD Programmes must continue to attract Global Hubs and, especially, Gatekeepers which play the role of Hubs both globally and locally in Europe. Moreover, the global reach of IST-RTD Programmes should be expanded by inviting foreign actors to play an active role in the Programmes, and by extending funding to foreign organisations. Local (European) concentration of funding can only produce European knowledge hubs, but not global knowledge hubs.

- *Support the further development of existing European IST Hubs and their entry into the top ranking of Global Networks.*

Hubs are characterised by research and technological excellence, they tend to be larger organisations with widespread resources, multi-talented teams and competencies that span several fields, have significant organisational capabilities for network coordination, and hold strong market positions. These characteristics turn them into desirable partners and place them into core positions in the network. Therefore, it is essential that more Global Network Hubs are based in Europe. Public policy aiming to create Global Network Hubs must include all policy measures that nurture and support globally competitive organisations that combine scientific and technological excellence and critical mass.

- *Investigate the causes of limited participation by smaller, highly dynamic companies in the IST-RTD Programmes and ways to encourage their participation. Nurture new European IST Hubs.*

Policy must not lose sight of the importance of industrial renewal in fast-paced environments such as IST. For the Framework Programme this means maintaining low barriers to entry for smaller, newer organisations. Such barriers typically relate to the administrative burden of participation, stretching from the proposal stage to financing, coordinating the RTD project, and reporting to the Commission. It also means identifying excellent SMEs, luring them into the Framework Programme, and supporting their growth into effective Knowledge Hubs.

- *Maintain funding Instruments with the characteristics of Integrated Projects (IPs) and Specific Targeted Research Projects (STRePs).*

IPs provide the breadth and scale to attract Gatekeepers, other Global Hubs and IST-RTD Hubs, reduce fragmentation and help reach critical mass. STRePs are reported by industry to be well focused, functional, and relatively easier than both IPs and NoEs to coordinate. STRePs are thus the instruments for well-focused research and are more manageable for SMEs. The role of both IPs and STRePs should be maintained.

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1. INTRODUCTION

1.1. STUDY OBJECTIVES AND FOCUS

This document reports the main results of a large-scale evaluation of the research funded by the Information Society and Technology (IST) Priority of the Community's Research Framework Programme. Conducted between January and December 2005, the evaluation primarily concentrated on project participants funded in the context of the first two IST Calls (2002-2004) of the Sixth Framework Programme (FP6). Three Thematic Areas were included in the analysis:

- Thematic Area 1 (TA1): Applied IST Research Addressing Major Societal and Economic Challenges
- Thematic Area 2 (TA2): Communication, Computing and Software Technologies
- Thematic Area 3 (TA3): Components and Micro-Systems

For comparative reasons, some parts of the evaluation also dealt with the corresponding IST Key Actions of the Fifth Framework Programme (FP5), including "Systems and Services for the Citizen", "New Methods of Work and e-Commerce", and "Essential Technologies and Infrastructures". Moreover, the contractor built large longitudinal databases around the IST-RTD data provided by the Commission to capture the global networking relationships in the examined technological fields. These databases reflected the global alliance and European patenting activity of organizations which participated in the examined Thematic Areas and others that did not, thus providing a point of reference for the networks built through the Framework Programme.

The evaluation applies social network analysis to assess:

- In what IST domains European organizations are leading "knowledge hubs"
- How Integrated Projects (IPs) and Networks of Excellence (NoEs) are positioned in global networks
- What makes "knowledge hubs" effective and how to better facilitate the continuing success of existing hubs and the development of new leading hubs
- The extent to which IST-RTD collaboration networks are sufficiently inclusive of national research networks and key large and small IST enterprises
- The association between networks of collaboration, dissemination and exploitation of knowledge with the mobility of scientists and engineers across organizations

In order to address such questions, the evaluation has developed and applied a quantitative methodological framework for high-quality, comparative assessment of inter-organizational networks established by IST-RTD programmes with global networks developing independently of Community funding. In addition, more qualitative information obtained through a series of expert/practitioner interviews is utilized to calibrate some of the results and obtain stakeholder suggestions for the future. The evaluation purports to demonstrate the applicability of social network concepts and analytical tools in appraising the relative positioning of IST-RTD networks and their effectiveness in creating leading knowledge hubs in selected technological domains.

1.2. STUDY CONTEXT

1.2.1. IST-RTD Evaluation

The IST Priority has been a core area of the Research Framework Programmes since their initiation in the early 1980s. This investment 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 FP5 that has continued in FP6. IST has maintained a leading position among all Thematic Priorities of the successive FPs for obvious reasons: it is a core piece in the policies of the Community striving to establish the leading knowledge-based economy in the world (Lisbon agenda).[1] The IST Thematic Priority has thus commanded a large share of the FP throughout the years,[2] amounting to almost a quarter of overall funding in the FP6.[3]

Europe has achieved significant benefits from the IST investment, many of which have been captured in the periodic evaluation exercises such as the latest 5-year assessment of the Programme.[4] The Community has high expectations for the contribution of its investment in information technology and media to competitiveness, economic growth and employment as it is stressed in the renewed Lisbon Strategy and the plan i2010.[5]

The decision for FP6 explicitly tasks the Commission to continually and systematically monitor the overall Programme and its specific areas such as the IST Thematic Priority. Such monitoring aims at a systematic analysis of the inputs, outputs, and outcomes of the IST Thematic Priority actions to provide a well-founded judgment regarding the achievement of the operational objectives and a reasonably substantiated opinion regarding future investments in IST-RTD. The Framework Programme as a whole and its constituent parts are now subject to systematic appraisal that includes all three legs of the evaluation:

- Priority setting and ex ante impact appraisal
- Monitoring of progress – interim evaluation
- Evaluation of results (ex post)

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1 See, for example, "Working Together for Growth and Jobs: A New Start for the Lisbon Strategy", Commission Communication to the Spring European Council, COM (2005) 24, February. Also, reports on next steps to intensify the effort such as "Facing the Challenge: The Lisbon Strategy for Growth and Employment", Report from a High level Group Chaired by Wim Kok, November 2004 (Kok Report).

2 IST is the only Thematic Priority with a specialized DG devoted to it.

3 See budget allocations at http://fp6.cordis.lu/fp6. RTD project funding represents more than half of the total budget. IST allocations reach approximately 29% of the funding for cooperative RTD in the Commission's recent proposal for the next Framework Programme (FP7). Commission Proposal for a decision of the European Council and the European Parliament concerning the seventh Framework Programme of the European Community for research, technological development and demonstration activities (2007-2013) "Building the Europe of Knowledge", COM (2005) 119.

4 For example, "Five-Year Assessment 1999-2003: Research and Technology Development in Information Technologies", Final Panel Report, January 2005 (Cago Report). For further information on the evaluation of the IST TA see http://europa.eu.int/comm/dgs/information_society/evaluation/studies.

5 Communication from the Commission "i2010 – a European Information Society for growth and employment", SEC(2005)717. Communication to the Spring European Council "Working together for growth and jobs: A new start for the Lisbon strategy", COM(2005) 24, 2/2/05.

The Commission reforms in the past few years have made such activities even more important in an effort to enhance accountability and transparency, initiate regular ex ante appraisals of proposed programmes, further extend programme monitoring and ex post impact assessment, and improve the communication of program activities and outcomes to policy decision makers and sponsors. DG Information Society and Media, and its evaluation unit C3, have been at the forefront of these developments. This report falls within their on-going plan of evaluation, especially evaluation using the new social networks analytical tools.

1.2.2. Network Analysis for IST-RTD

Network analysis has recently emerged as a very desirable complement to more traditional evaluation approaches for RTD programmes for reasons better elaborated in Section 2 below. This is the third evaluative study utilizing the networks methodology for the IST-RTD function of DG Information Society and Media. The studies have progressively grown more sophisticated and theoretically precise in the sense of empirically testing specific hypotheses.

This evaluation, then, fits within the particular evaluative context of DG INFSO and follows two earlier studies applying network methodologies by the Josef Stefan Institute and RAND Europe.[6] The two earlier studies have made significant steps in mapping the IST research networks in Europe and examining the topological features of such networks. Those studies indicated 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;
- 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 or EUREKA

This evaluation complements those earlier studies and significantly expands the scope of using the network methodology for evaluation purposes by examining in greater length the IST-RTD networks and by comparing them to the global networks. The evaluation 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, the inclusiveness of core national research organizations, and the mobility of scientists and engineers.

[6] J. Stefan Institute study: "Data Mining and Decision Support for Business Competitiveness: A European Virtual Enterprise" (Cordis Project reference: IST-1999-11495). RAND study: "ERAnets: Evaluation of Networks of Collaboration between Participants in IST Research and their Evolution to Collaborations in the European Research Area (ERA)", March 2005 (Tender OJ 2004/S 177-151255).

1.2.3. Organisation of the report

The report is structured as follows. Section 2 illustrates the rationale for a network approach to evaluating IST-RTD Programmes and provides a description of the methodology adopted and data used. Section 3 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, the inclusiveness of core national research organizations, and the mobility of scientists and engineers. Section 4 summarizes the results and offers policy recommendations.

Finally, it must be emphasized that a *Technical Report* has also been prepared as a separate companion document of this report. The Technical Report presents the findings in their technical detail and provides an in-depth overview of the methodology, a social network glossary, the underlying theoretical framework, and literature references.

2. NETWORK APPROACH RATIONALE AND METHODOLOGY

Perhaps the most striking feature of industrial innovation today is that it is largely a collaborative activity. Most innovations involve a multitude of organisations. This is especially the case for the most valuable, most knowledge-intensive, and most complex technologies such as information technology, biotechnology, and advanced materials.

Innovation networks are increasingly regarded as the dominant organisational mode in the knowledge-based economy. Adapting to an environment of high risks, global competition, increasing cost and complexity of different technological advances, and rapid generation and diffusion of technical knowledge and know-how, large numbers of firms, universities and other research organizations have opted for cooperative relationships. These linkages are very complex, involving not only diverse kinds of formal contracts, but also informal exchanges of knowledge. In the presence of technological development that involves a greater array of product and process systems, subsystems, and components, no single firm can deploy all of the required core capabilities and complementary assets at a reasonable cost. In this context, a network serves as a locus for innovation because, for any network member, it provides timely access to external knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning abilities.

2.1. THE FRAMEWORK PROGRAMME AS A NETWORKING ENVIRONMENT

The European Research Framework Programme (FP) is the main policy instrument of the Community for research and technological development (RTD). 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. Since the early 1980s, successive FPs have tried to achieve these objectives by promoting collaborative research.

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 respective objectives by promoting collaborative research, a procedure put in place in the early 1980s when the FP was being 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:[7]

- **Integrated Projects** (IPs) are large projects with holistic workplans that connect a range of research, development and deployment activities. They have limited internal flexibility. Overall workflow is fairly well laid out from the beginning. The coordinating organisation has a key role and mediates participation – and thus has most "bargaining power". IPs are likely to involve a wide range of organisations from the research and business communities. In some cases, work is more modular than collaborative.
- **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. Their internal financing provides strong incentives for active and ongoing collaborative efforts. They are more likely to involve publicly-supported research organisations and to have less centralised or hierarchical structures. NoE research is perhaps more likely to favour "out-reach" collaboration beyond the original network.
- **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 and the closest Instrument to the typical collaborative research that has been 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.

2.2. NEW EVALUATION CONCEPTS AND NETWORKS

Public support for RTD has been justified in the economics literature on the basis of market failures and system 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.[8] More recently, analysts have also promoted the rationale of 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 efficiency of mechanisms facilitating knowledge flows.

[7] Summary descriptions are based on "ERAnets: Evaluation of Networks of Collaboration between Participants in IST Research and their Evolution to Collaborations in the European Research Area (ERA)", Final Report by RAND Europe, DG Information Society and Media, March 2005, pp.7-8.

[8] Spillovers may be caused by three factors. One is the inability of the private party to charge a high enough price that will extract the full additional value to the buyer of the new/improved product or process (pecuniary spillover). Another is the inability of the private party to fully appropriate the new knowledge (knowledge spillover). Yet another is the inability to charge partners in complex systemic products for the opportunities the party in question creates to them for innovation (network spillover).

Systemic failure arguments have highlighted the inadequacy of the traditional approaches to evaluate RTD projects and programmes. It is advocated that just accounting for inputs and outputs and/or outcomes leaves relatively untouched the dynamics of RTD and innovation, i.e., the processes involved in generating innovation outcomes from a systems' point of view that is non-linear, networked and with multiple feedback loops. 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.

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?
- *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 competences, capabilities, organization and strategies of firms?

It is the third aspect of additionality where traditional economic approaches have had a particularly difficult time to approximate. It is exactly this 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 so forth, 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.

Working in this vein, the present evaluation primarily relates to the third concept of (behavioural) additionality while also partially addressing the second concept of (output/outcome) additionality. The analysis largely reflects an empirical analytical methodology for systematic:

(i) collection, classification and coding of extensive network data at the organization level relating to IST-RTD activities, and
(ii) analysis of the role of DG INFSO funding in setting up effective knowledge hubs that nurture global knowledge leadership and European cohesion in the examined RTD domain(s).

Policy recommendations also reflect to some extent lessons from a number of interviews with industry experts and our understanding of the general policy environment.

2.3. STUDY METHODOLOGY

2.3.1. Network data

This evaluation uses large-scale quantitative data on the participation of European organisations in various knowledge-related collaboration activities. In this sense, the data used are *objective* as they are not derived from surveys or self-reported questionnaire data. In addition, a series of expert/practitioner interviews have been utilized to calibrate and corroborate some of the results obtained and gather stakeholder suggestions for the future.

This study examines four types of network relations as illustrated by the following table.

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 (Thomson Financial)
Knowledge Network	Knowledge network arising from cross-organisational patent citations	EP-CESPRI dataset (European Patent Office)
Mobility Network	Network arising from cross-organisational mobility of scientists and engineers	EP-CESPRI dataset (European Patent Office)

The construction of these four networks required a thorough preliminary work for standardising and matching the names of organisations across the different sources of data. Moreover, a consolidation of firms at the level of ultimate parent company was also required in order to identify subsidiaries of multinational corporations (MNCs).

The IST-RTD Network provides the core network of this evaluative study. It is complemented by the analysis of three broader networks within which knowledge and resources are exchanged and transferred. In other words, the purpose of this study is to place the IST-RTD Network within the context of the broader networks of knowledge relations spontaneously emerging from the initiatives of individual organisations. On the basis of information available to us, we build two networks for IST-RTD projects: the IST Applications Network, which includes projects in Thematic Area 1, and the IST Development Network, which includes projects in Thematic Areas 2 and 3.

Examining the Global Network of strategic alliances allows 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, 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.

Box 1 – Partnership Network
The network formed by collaborative RTD projects can be studied as an affiliation network (or bipartite graph), i.e. a network in which actors (organizations) are joined together by common membership to groups (collaborative RTD projects). Affiliation networks can be represented as a graph consisting of two kinds of vertices, one representing the actors and the other the groups. In order to analyse the patterns of relations among actors, however, affiliation networks are often represented simply as unipartite (or one-mode) graphs of actors joined by undirected edges. In this study, we refer to the analysis of the unipartite graph of organizations involved in RTD consortia, although this representation may miss some relevant information.

The data used to construct IST-RTD network has an important specific feature. Unlike other affiliation networks that have been recently examined (for example, scientific co-authorship, CEOs of companies), the dataset used here contains some additional information about the role played in each RTD project by different organizations. More specifically, in each project we can identify the organization acting as Prime Contractor. Considering the importance of these organizations, that prior analysis has shown they tend to participate much more frequently than others and they have more central positions in the network, and that it is likely that organizations involved in large R&D consortia know the coordinator better than they know each other, an alternative way of representing the unipartite graph is the 'star' network.

According to the latter hypothesis, Prime Contractors would then act as intermediaries in the flows of knowledge between partners in the same RJV and no direct edge would exist between partners (Star assumption). Both assumptions about the role played by Prime Contractors are, of course, rather strong and somewhat arbitrary.

Following the *RAND Europe* study, we have focused our analysis on networks in which all partners are treated the same. However in the *Technical Report* we have checked the robustness of the results obtained also considering the alternative assumption.

An important channel of knowledge transfer is represented by the disembodied flow of scientific and technical information, i.e. knowledge spillovers. Although capturing this type of knowledge flows in their totality is difficult, a reasonable approximation frequently used in the economic literature involves the citations to prior art patents contained in patent documents. The fact that patent A cites patent B as prior art is an indication of some kind of knowledge flow from the organisation responsible of patent B to the organisation responsibe 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. The analysis of the Knowledge Network aims 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.

Another extremely important channel of knowledge diffusion and recombination is through the mobility of skilled human capital across organisations. Evaluating the role of this diffusion channel is often difficult due to the lack of data. In this study, we overcome these difficulties by examining the patterns of mobility across organisations of scientists and engineers reported as inventors of patents. In particular, the fact that a significant number of inventors move from company X to company Y means that company X is an important source of embodied knowledge for company Y. Moreover, to the extent that company X is a significant receiver and sender of human capital for a large number of other organisations, then, company X plays a key brokerage role in the process of knowledge diffusion.[9] The analysis of the Mobility Network thus permits to evaluate whether and to what extent European organisations involved in IST-RTD projects are also effective knowledge brokers.

It is worth stressing that to our knowledge this is the first evaluative study attempting such a large scale integration and comparison of different network data.

Box 2 – Measuring knowledge flows with patent data

Besides data on participation in IST-RTD projects and on the broader global network of strategic alliances in IST related domains, this evaluation report makes use of patent and patent citations data. The advantages and limitations of patent data as indicators of *inventive output* are well known and can be shortly summarised. On the one hand, not all inventions are patentable and patented inventions differ greatly in their economic value; the propensity to patent varies greatly across industries and firms. Other means of appropriability (such as secrecy and lead times) may be more effective than patents at times. There are major differences among countries in procedures and criteria for granting patents. Finally, patents capture only imperfectly advances in software technology. On the other hand, patent data are available in the form of long time series and provide extremely detailed technological information on the invention. They also provide valuable information on the company and on the individuals responsible for the invention and allow international comparisons. Finally, they are a more satisfactory indicator of innovative activity of SMEs than R&D statistics.

In addition to these well known features, patent data have been increasingly used in recent years as indicators of *knowledge flows*, rather than inventive output. In particular, several authors have argued that patent citations (i.e. references contained in a patent document to previous patent documents) can be used to track the flows of knowledge across individual scientists, firms and countries, as they provide (paper) trails of the *knowledge link* between inventions. In other words, the fact that a patent cites a previous patent as prior art is taken to indicate that the previous patent embodies knowledge that has been essential to develop the latter invention. Patent citations thus capture the cumulative nature of technical change.

The use of patent citations has been criticised on the ground that most of the citations reported in patent documents are made by patent examiners and therefore neither the inventor nor the assignee of the current patent may be aware of the cited patents. Notwithstanding these problems, patent citations have been increasingly used to measure the value of patented inventions and to track the linkages between science and technology. A particular use of patent citations, which has been pioneered by Joel Podolny, Toby E. Stuart

[9] The extreme example of such a phenomenon is Fairchild whose employees played a core role in establishing several of the central companies growing in and around Silicon Valley in the United States a few decades ago.

and Michael Hannan, exploits the *relational* nature that is implicitly defined by the citation linkage. More specifically, whereas the typical unit of analysis in most research on patent citations has been the individual patent document, by counting for example the number of citations received by a patent, or the dyad "citing patent-cited patent", this approach moves up the analysis to the dyad "citing organisation-cited organisation". By considering all pairs of organisations linked by a patent citation relationship, it thus becomes possible to map the overall network of knowledge flows among patenting organisations (or individual scientists).

Apart from a few pioneering studies, the analysis reported in the present evaluation is, to our knowledge, the first large scale attempt at using patent citations data to examine the network of knowledge flows in IST related technological domains.

2.3.2. Analytical Methodology

Throughout this study, analysis is conducted at the level of individual organisations (rather than at the country level or at the level of individual researchers). Three basic types of organisations are considered: private companies (IND), higher education institutions (HE), and public research organisations (REC).

The main analytical tool used in the study is graph theory and its applications, also known as social network analysis. This section briefly illustrates the key terminology and the main concepts of social network analysis adopted in this study, explicitly referring when necessary to the actual data used.[10]

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 graph (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 the context of this study, nodes are organisations, while relational ties are of four different types (see table above):

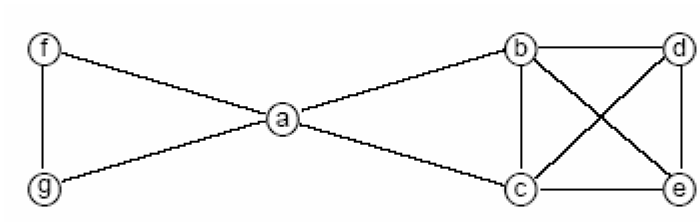
- organisations *a* and *b* are linked by an edge if they have been partners in at least one IST-RTD project (IST Applications Network and IST Development Network)
- organisations *a* and *b* are linked by an edge if they have been partners in at least one strategic alliance (Global Network)
- organisations *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)
- organisations *a* and *b* are linked by an edge if organisation *a*'s inventors moved to (or came from) organisation *b* (Mobility Network).

To keep the analysis as simple as possible, we use only undirected and binary valued networks. This means that we disregard both the direction and the intensity of the ties linking pairs of organisations. To do otherwise would require much more data that are

[10] See *Technical Report* for a network glossary.

currently unavailable (e.g., on the intensity of collaboration between organisations *a* and *b* in a network versus organisations *a* and *c*).

The following sociogram illustrates a hypothetical network, where nodes represent organisations and edges may be thought of as capturing any of the relational ties just described. The example provided is only instrumental and purports to convey the basic understanding and intuition of the key notions of social network analysis used in the following sections.



A core concern of this study is to examine the position occupied by different types of 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 the 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 unconnected. Hubs have therefore an extremely important role in partnership and knowledge networks, such as the networks investigated here, 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 where nodes represent organisations, degree centrality is therefore defined as the number of other organisations with which the focal organisation has a relational tie.[11]

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.[12]

[11] With reference to the hypothetical network depicted above, nodes *a*, *b* and *c* present the highest values of degree centrality being connected to four other organisations.

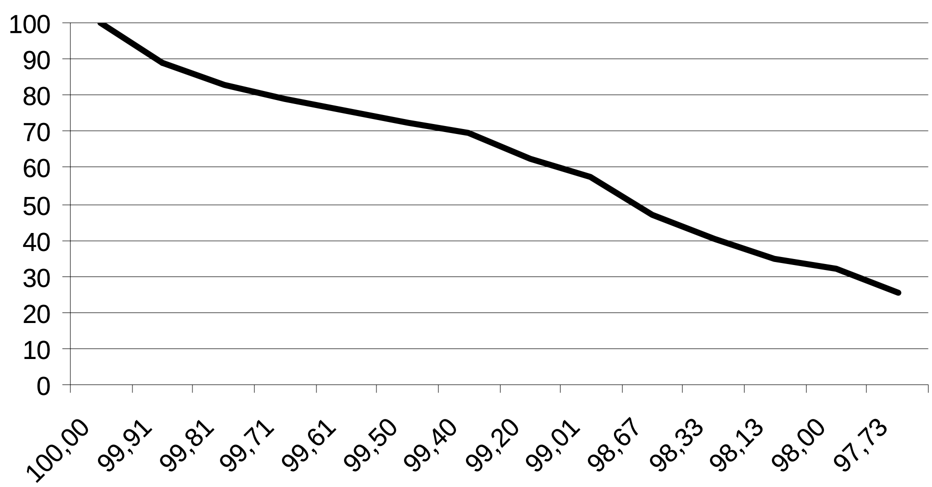
[12] With reference to the hypothetical sociogram depicted above, is intuitive that node *a* has a high influence as a network connector. For example, the shortest path between organisations *d* and *g* has length 3 and organisation *a* lies on it. If one takes all possible pairs of organisations (excluding *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

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.[13]

Box 3 – The role of Hubs in keeping connected networks

"*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-Laszlo Barabasi.

The idea developed by Barabasi in several studies and summed up in his previous quote could be easily also 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.



Note: the size of the Global Network giant component is set equal to 100.

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 (i.e. those connecting node *d* with *a*, *f* and *g*) and it is thereby characterised by a lower value of betweenness centrality (0.20).

[13] The two per cent cut-off is obviously arbitrary but this arbitrariness in the cut-off value is hard to avoid in similar exercises. However, we considered different values (both higher and lower then two per cent) in order to check for robustness. The main results seem to be not affected, since they are based on the role of some organizations that result to act as Hubs independently on the chosen value. Alternatively, Hubs could have been defined on the basis of threshold values for centrality. This becomes impractical, however, because of the need to compare across different types of networks of different sizes.

This procedure has been separately applied for each type of relational tie. This defines four types of Hubs, each corresponding to one of the four kinds of networks considered herein:

- 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)
- Mobility Hubs (318 Hubs for the Mobility 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**. A Gatekeeper is defined to be an organisation which plays the role of Hub in more than one network.

3. FINDINGS

3.1. VARIOUS TYPES OF ORGANISATIONS PLAY THE ROLE OF HUBS IN IST-RTD NETWORKS

One of the aims of FP6 is 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. The full list of Hubs is reported in the Appendix (Tables A1 and A2).

Table 1 reports the distribution of Hubs by organisational type for the IST Applications Network and the IST Development Network [14] 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 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.[15]

Table 1: 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

[14] 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.

[15] As mentioned in the methodological section, 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 do not change in a substantial way and are therefore relatively not sensitive to the consolidation of companies and research laboratories.

3.1.1. *The type of Hub differs across Instruments*

If the linkages formed by NoEs are excluded, the role of industrial organisations as Hubs becomes relatively more important: it accounts for 55% of all Hubs in the IST Applications Network and around 45% of all Hubs in the IST Development Network (Table 2). This result would seem to depend on two factors. First, NoEs host a larger proportion of participants from higher education institutions and public research organisations. Second, the propensity of different organisations to take a leading role in projects 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.

Table 2: Type of Hubs in IST-RTD Networks (excluding NoE)

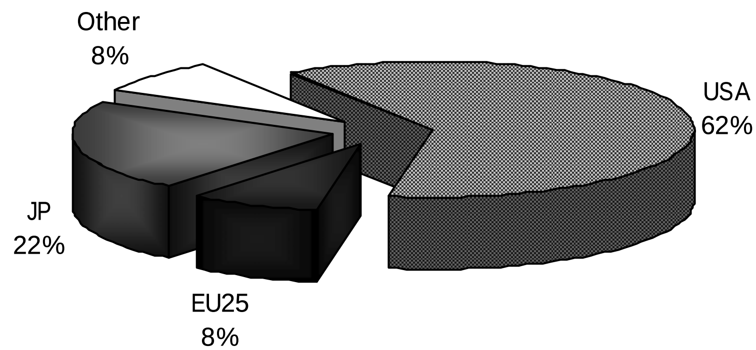
	IST Applications Network		IST Development Network	
	Participants (%)	Hubs (%)	Participants(%)	Hubs (%)
Higher Education	20.2	23.5	26.3	21.0
Industry	39.0	55.3	44.9	48.2
Research Centre	13.0	21.2	16.0	30.8
Others	27.8	0	12.8	0
Total (%)	100	100	100	100
Total (abs value)	1399	33	900	23

3.2. The most important Global Hubs are involved 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 links, connections and collaborations, directly and indirectly, with the major global network players. Are the most important Global Hubs involved in IST-RTD Networks?

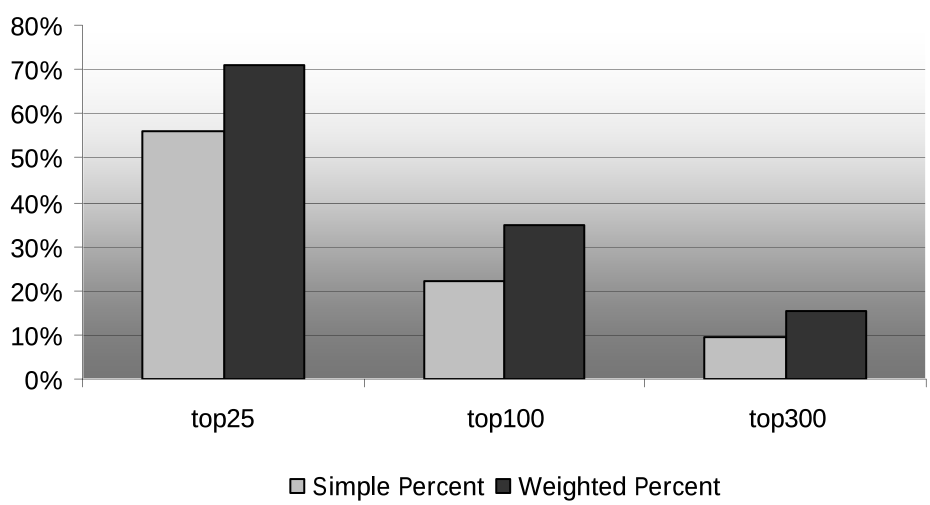
Figure 1 shows the geographical distribution of Hubs in the Global Network. Few of them are European. Even discounting the US dominance, few European organisations are able to occupy core positions in the global ICT alliance networks.

Figure 1. Distribution of Top 100 Global Hubs by area



At the same time, there are also strong indications that IST projects are able to attract Global Hubs. Figure 2 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 2. Percent of Global Hubs participating in IST projects



3.3. A LARGE NUMBER OF GLOBAL HUBS ARE ALSO HUBS IN THE IST-RTD NETWORKS

The success of the IST Thematic Priority in attracting key global players is reinforced by the fact that some of the Global Hubs are also Hubs in IST-RTD Networks. These nodes (mostly, firms) play the critical role of Gatekeeper as they are able to effectively put in contact organisations involved in IST-RTD with the broader global network of RTD collaboration. The position occupied by these nodes 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 3 and 4 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.

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

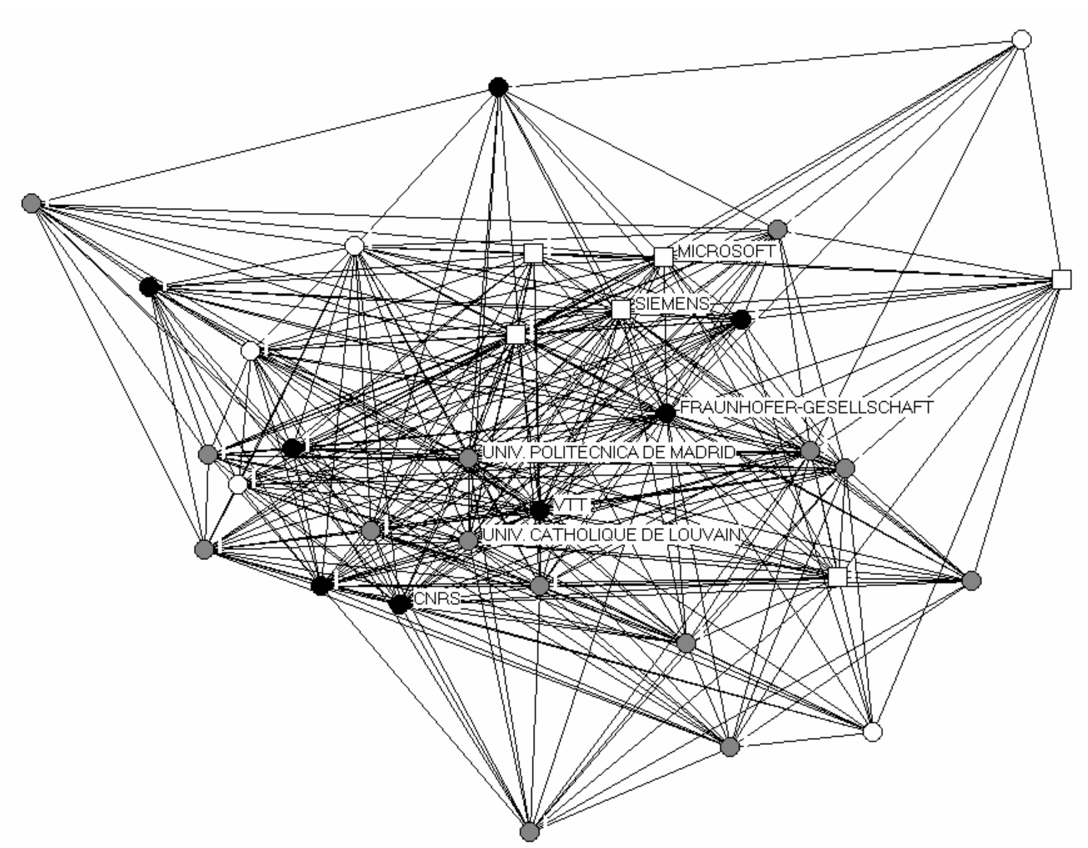
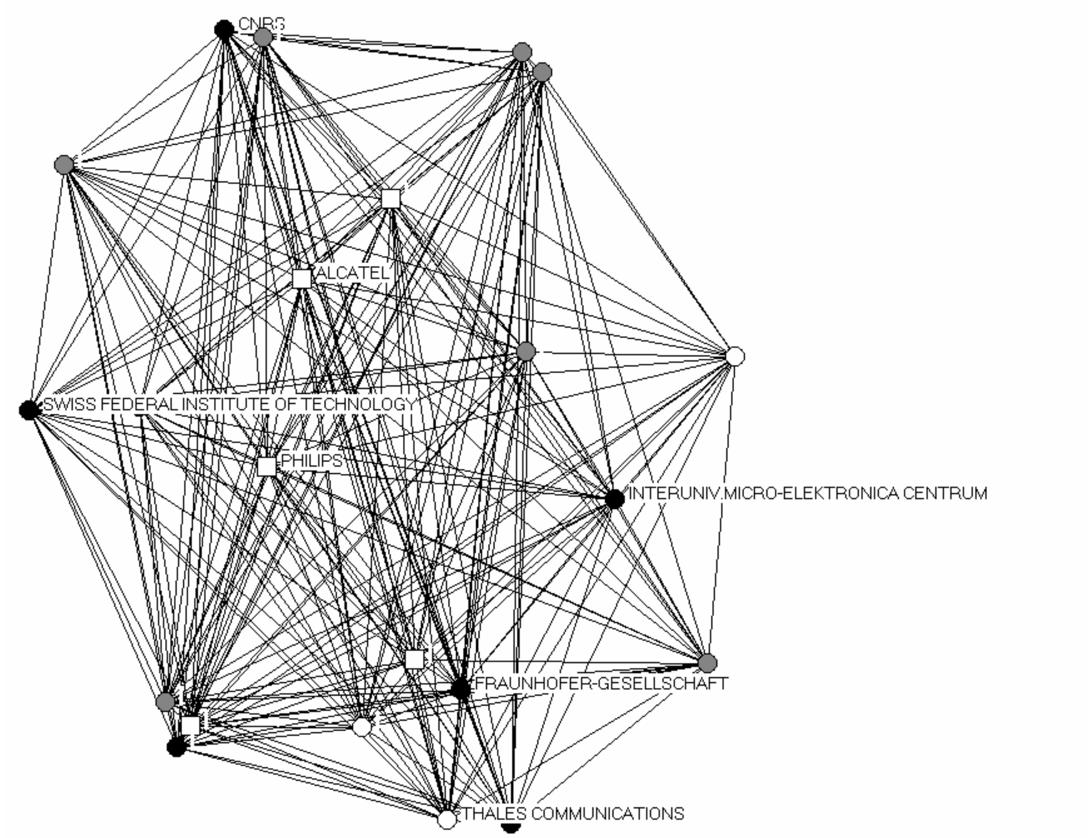


Figure 4. IST Development Hubs
(white=industry, grey=university, black=public research centre)
(○=IST-RTD Hub, □=Gatekeeper (IST-RTD *and* Global Hub))



3.4. IPs ARE HIGHLY EFFECTIVE INSTRUMENTS FOR CONNECTING IST-RTD ORGANIZATIONS AND GLOBAL HUBS

We start by examining the fraction of all linkages between pairs of actors accounted for by the three major funding instruments of Framework Programmes: Integrated Projects (IPs), Networks of Excellence (NoEs) and Specific Targeted Research Projects (STRePs)[16]. The results are reported in Figures 5 and 6 for the IST Applications Network and the IST Development Network respectively. As expected, 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.

[16] The values of Coordinated Actions and Specific Support Actions are not reported,

Figure 5. IST Applications Network
percent of projects and links depending on them

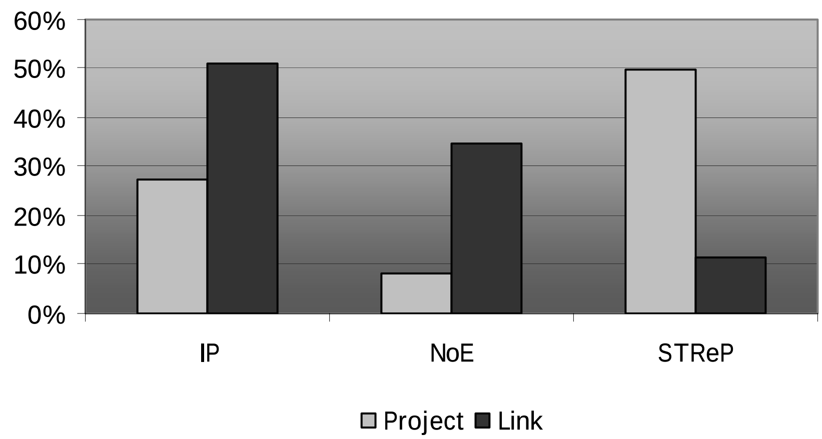
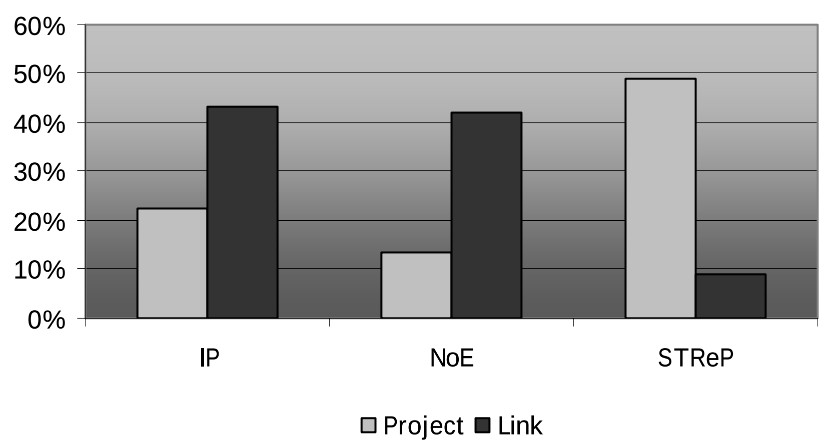


Figure 6. IST Development Network
percent of projects and links depending on them



How effective are the various funding instruments in linking IST project participants to Global Hubs? To answer this question, 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, Gatekeeper, Global Hub, and Other IST-RTD Organisations. And, in terms of Instruments, we consider IPs, NoEs, and STRePs.

Results are reported in Figures 7 and 8 for the IST Applications and the IST Development Networks respectively. The figures report 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 organisations that are Global Hubs (but 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.

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 examined networks.

Another way to test the importance of IPs in connecting populations 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 9.

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 could be considered a strength of this Instrument in terms of promoting the ERA objectives. There was discussion in our expert interviews about fragmentation and lesser global reach by European IST-RTD companies. IPs would 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 provides connectivity to the best and brightest in the world.

Figure 7. Relative importance of IPs, NoEs and STRePs in bridging IST Applications Network Organisations

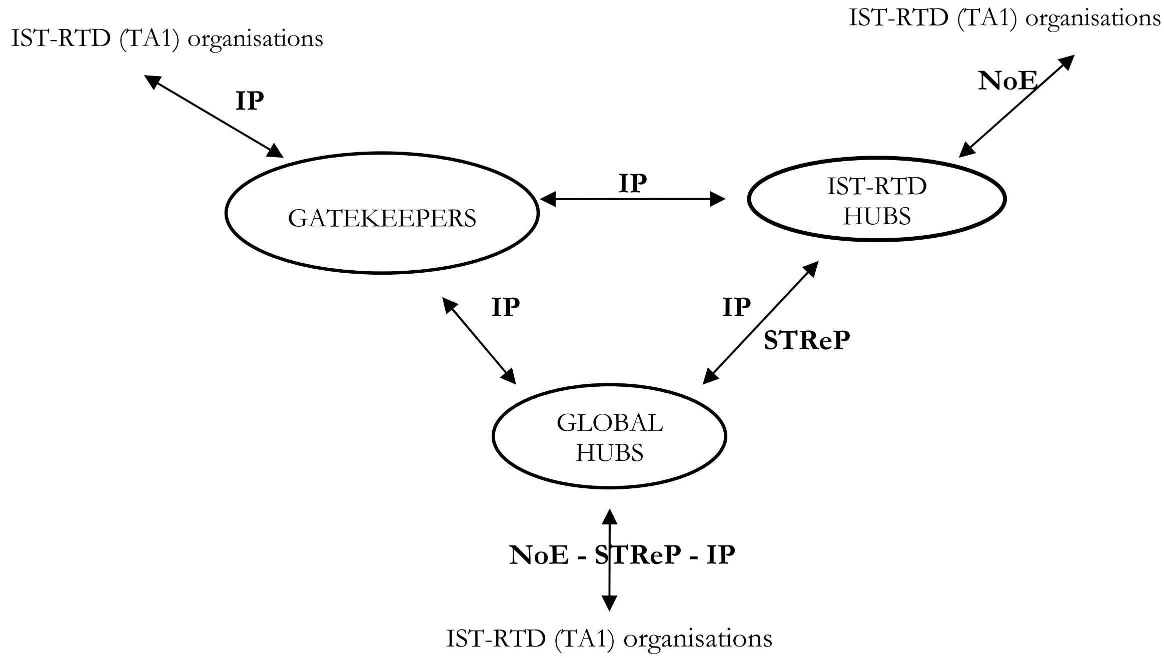


Figure 8. Relative importance of IPs, NoEs and STRePs in bridging IST Development Organisations

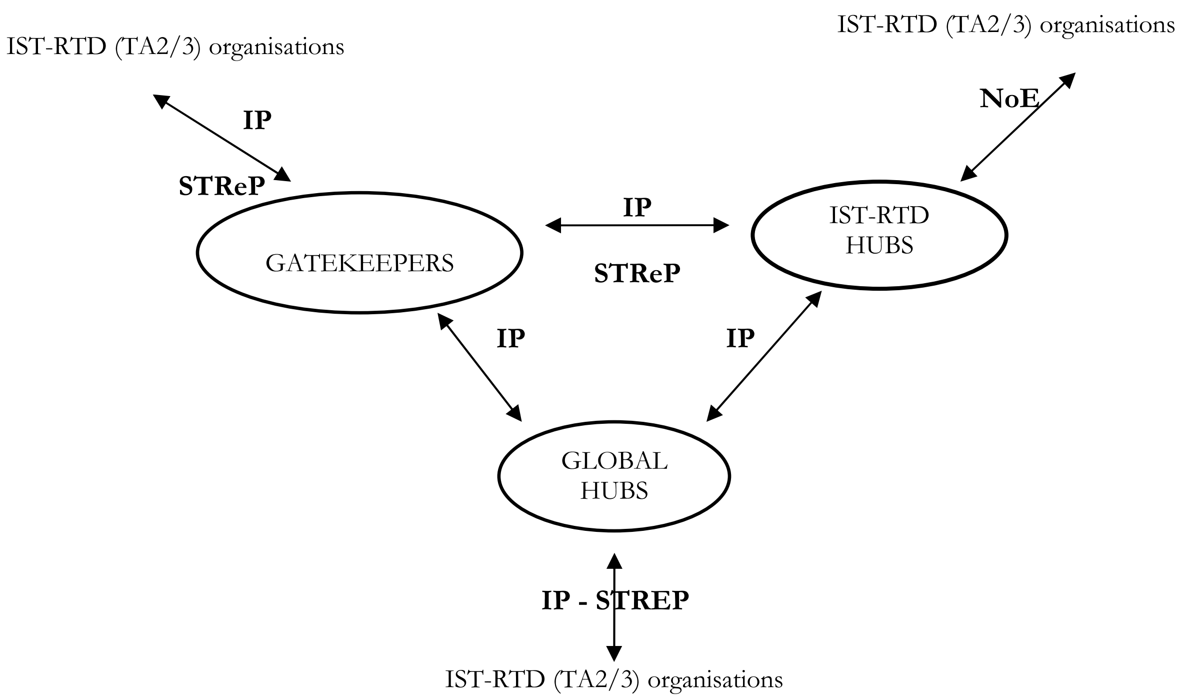
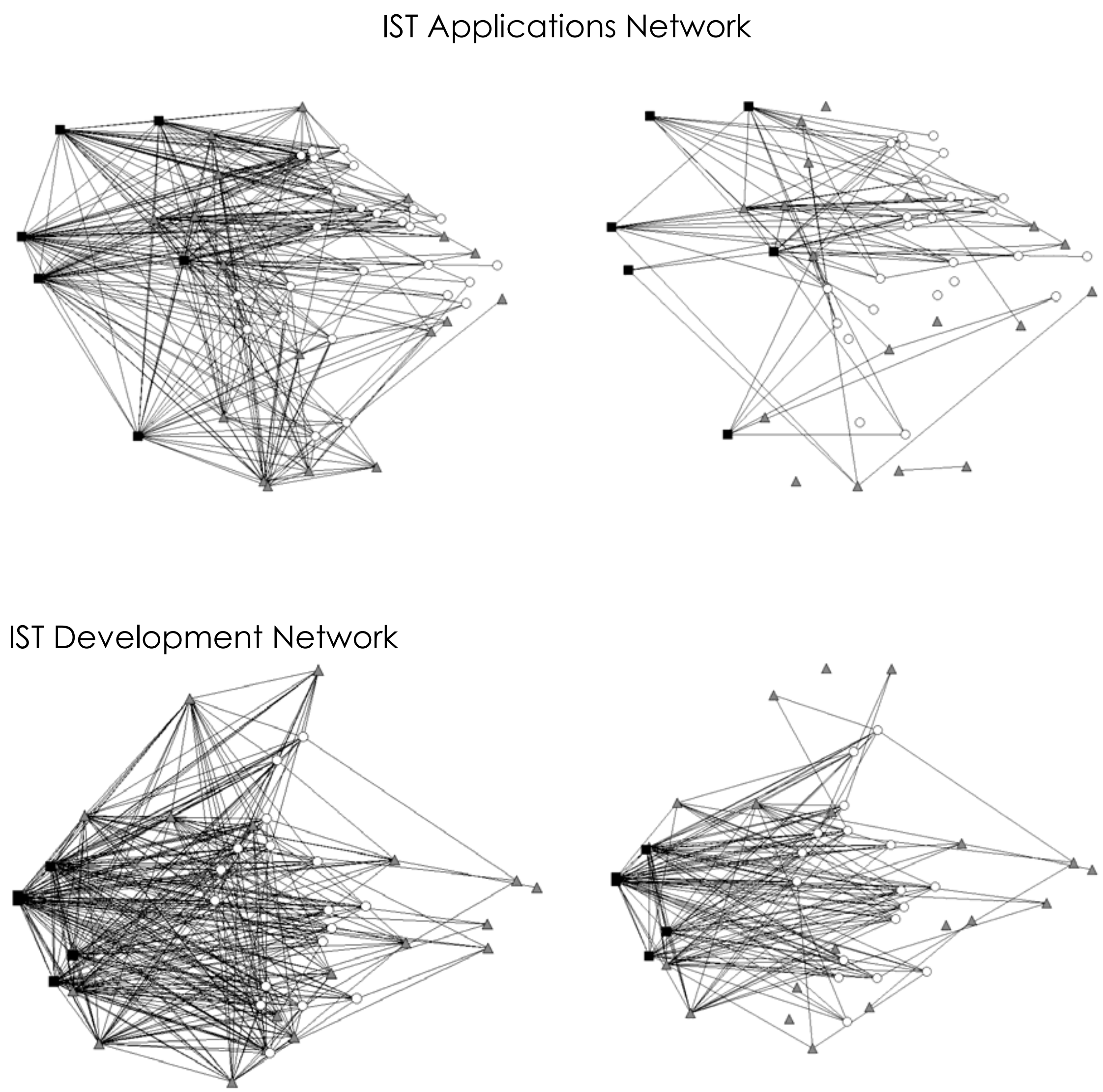


Figure 9. Linkages among Hubs in the IST-RTD Networks
with IPs (left panel) and without IPs (right panel)
[○=IST-RTD Hubs only, ■ = Gatekeepers, ▲= Global Hubs only]



Our interviews highlighted the fact that IPs are considered the turf 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 reported as 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 play an important role in IP networks by focussing on more long-term and fundamental parts of the research. The promotion of more intensive knowledge transfer between university and industry was considered 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. As previously mentioned, 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).

3.5. HUBS ARE EFFECTIVE AT VARIOUS LEVELS: PRODUCING AND DIFFUSING KNOWLEDGE AND GENERATING MOBILITY OF SKILLED HUMAN CAPITAL

Section 3.1 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.

This has prompted us to consider the inventive record of each partnership Hub and its role in diffusing and exchanging the accumulated knowledge as reasonable proxies to evaluate 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.

In this investigation, we have used the EP-CESPRI patent database to measure inventive activity and to derive indicators of knowledge diffusion and human capital mobility. It is important to note that we used all patent applications to the EPO in the fields related to IST technologies. In this sense, the coverage of the patent database is global.

3.5.1. IST-RTD Hub effectiveness in producing and diffusing knowledge

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** (weighted by the number of patents): number of citations received by patents of an organization divided by the total number of patents of that organization. It is a measure of quality of the patent portfolio of an organisation.[17]
- **Number of Highly Cited Patents**: number of frequently cited patents.[18] 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 the basis of this network, we have calculated for each organisation, 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[19] are more inventive and more central than other IST-RTD organizations, thus being quite effective in both the generation of new knowledge and diffusion of existing knowledge (Figure 10, top panel). More interestingly, IST-RTD Hubs are also more effective in the generation and diffusion of knowledge and inventiveness than Global Hubs (Figure 10, bottom panel).

Further investigation also reveals the following (see *Technical Report*):

- The Global Hubs that participate in IST-RTD are more effective in every respect than those that do not participate. The FP is able to attract Global Hubs that are relatively more effective in terms of both producing and diffusing information.

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[17] Companies self citations are excluded.

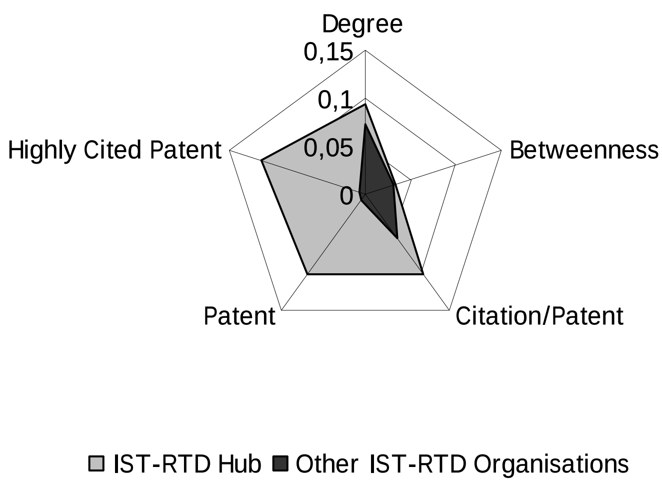
[18] In order to select highly cited patents, we consider different cohort of patents (e.g. patents in Audiovisual Technology in 1999) and the citations received by each patent (e.g. citations made from patents from 1999 ahead) . The top five per cent of patents of each cohort has been considered as highly cited.

[19] In this section, IST Applications and IST Development Hubs are examined jointly.

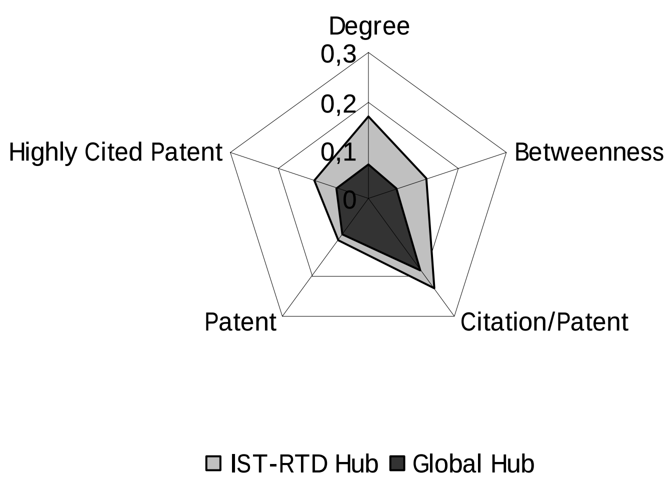
- Global Hubs that are also IST-RTD Hubs (i.e. Gatekeeper organisations) are relatively more effective than those Global Hubs which just participate in IST-RTD but play no major role in it.
- Gatekeepers compare favourably to organizations that are only IST-RTD Hubs.[20]

Figure 10. Effectiveness in producing and diffusing knowledge

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



IST-RTD Hubs vs. Global Hubs



[20] This result reflects to a significant extent the presence of a very large proportion of universities and research centers in the IST-RTD Hub group.

The analysis so far considers 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 our results when considering only firms.[21] The results prove to be quite robust: they hold as reported above.

The importance of Hubs is related to the scale-free nature of the examined networks.[22] Scale-free nature implies that a relatively small number of Hubs – that is, organizations that are most highly sought after – 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 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.

3.5.2. IST-RTD Hub effectiveness in terms of mobility of skilled human capital

Knowledge disseminates in disembodied form (manuscripts, blueprints, patents and the like) and also embodied in products and processes. It also disseminates through people. How involved are IST-RTD Hubs in disseminating knowledge through human capital mobility?

Patent data has been used to address this question. This time we have used information on the individual inventors that produced patents. By recording the names of the inventors and the names of the organisations for which they produced patents, it is possible to track the career patterns of individuals and their movements from one organisation to the other. This permits to build a Mobility Network in which nodes are organisations. For any pair of organisations a tie exists if there has been a flow of inventors among them (relocation). On the basis of this network, for each organisation we have then calculated, the usual indicators

[21] On this point, see *Technical Report*.

[22] Earlier studies have shown that, similarly to about every other network that has been studied, IST-RTD networks are also subject to the phenomenon of "preferential attachment". See "ERANets: Evaluation of NETworks of Collaboration among Participants in IST Research and their Evolution to Collaborations in the European Research Area (ERA)", Final Report, RAND Europe, March 2005.

– degree centrality and betweenness centrality – that summarise their position in the mobility network and define network Hubs.

Results show that 18 out of the 41 Hubs in the examined IST-RTD Programmes can also be characterized as Mobility Hubs (Table 3). Besides occupying a central role in the IST-RTD network, these organisations are positioned strategically in the flows of knowledge embodied in scientists and engineers. Among the organisations that can be characterised as Mobility Hubs one does not only find private companies, but also research organizations and universities. This result is even more striking if one takes into account the lower propensity to patent of such organisations.

Table 3: IST-RTD Hubs that are also Mobility Hubs

Organisation	IST-RTD Hub
SIEMENS AG	TA1 & TA2/3
PHILIPS	TA2/3
IBM	TA1
ALCATEL	TA2/3
HEWLETT-PACKARD	TA1
MOTOROLA	TA1 & TA2/3
FRAUNHOFER-GESELLSCHAFT	TA1 & TA2/3
NOKIA	TA1
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	TA1 & TA2/3
FRANCE TELECOM	TA2/3
DAIMLERCHRYSLER AG	TA1
THALES COMMUNICATIONS	TA1 & TA2/3
INTERUNIVERSITAIR MICROELEKTRONICA CENTRUM	TA2/3
STMICROELECTRONICS	TA2/3
MICROSOFT	TA1
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE	TA1 & TA2/3
SCHLUMBERGER	TA1
VTT TECHNICAL RESEARCH CENTRE OF FINLAND	TA1 & TA2/3

3.6. IST-RTD INVOLVES NATIONAL HUBS

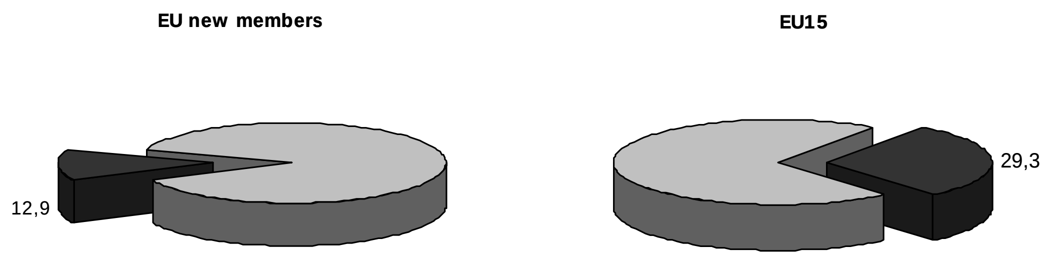
3.6.1. National Knowledge Hubs are included in IST-RTD Programmes

In order to assess whether National Hubs are included in IST-RTD programmes, for each of the 25 Member States of the European Union we have considered the top three Hubs in the Knowledge Network. We have then checked whether at least one of these organisations participates in the IST-RTD projects. This is true for most (11) of the EU15 Members, with the exception of Austria, Denmark, Luxemburg, and Ireland. However, it does not hold for New Member States: only 2 out of the 10 (Poland and Slovenia) have at least one national Hub in IST-RTD programmes.

3.6.2. National research centres in IST-RTD Programmes

The list of national research organisations compiled by the *World of Learning*[23] has been used to examine whether the major National Research Centres involved in IST-related activities are included in IST-RTD projects. The examined IST-RTD Thematic Areas were found to include a fairly good share of the national research infrastructure working on IST. Again this share is significantly higher for the 15 older Member States than for the 10 New Member States (Figure 11).

Figure 11. National Research Centres in IST-RTD



In addition, the National Contact Points in Member States were requested to list the two most important National Research Centres in their respective countries which allowed us to check their participation in IST-RTD projects. With the notable exceptions of the United Kingdom, Ireland, Cyprus and Estonia, the most important national research centres in Member States were found to be involved in the examined programmes.

3.7. IST-RTD INVOLVES INNOVATIVE SMES, BUT THERE IS STILL SCOPE FOR IMPROVEMENT

There is no question that IST-RTD involves innovative firms. But the introduction of the new Instruments has shown signs of squeezing out smaller organizations, some of which seem to turn into subcontractors instead of direct participants. The RAND Report claims that "*SMEs participate in FP6 research networks, but they are likely to be on the edges rather than in the centre. The SMEs are connected to instruments or projects through larger organisations.*"

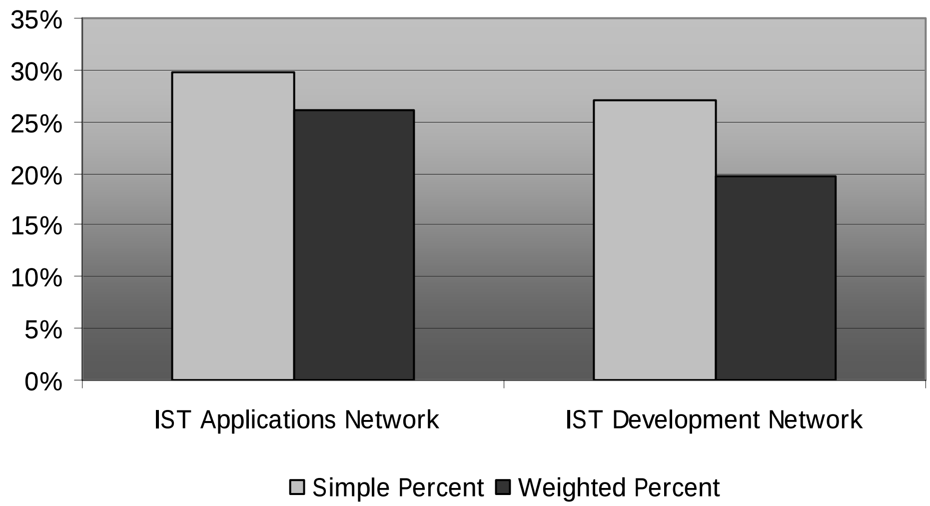
We have evaluated this statement by first looking at the role of small and medium-sized enterprises (SMEs) in the IST Applications Network and the IST Development Network.[24] No SME is an IST-RTD Hub. Moreover, while SMEs account for less than 30% of participant organisations funded by IST-RTD, their share is significantly lower if one weights their role by the ranking occupied in the network (Figure 12). SMEs account for 22% and

[23] www.worldoflearning.com

[24] Small and medium-sized enterprises (SMEs) are defined as enterprises which are independent (i.e. is not owned for 25% or more of the capital or voting rights by one or more enterprises falling outside the SME definition), have fewer than 250 employees, and have either an annual turnover not exceeding 40 million Euro, or an annual balance-sheet total not exceeding 27 million Euro.

16% of participations in the IST Applications Network and the IST Development Network respectively.[25]

Figure 12. Percent of SMEs among IST-RTD participants
(% of all organisations, and % weighted by ranking in the network)



SMEs also differ from their larger counterparts in terms of the chosen Instruments. The following two figures show the distribution of large organisations and SMEs among the three main funding Instruments.[26] Interestingly, relative participation in IPs is the most invariant with respect to firm size. That is not true for the other two Instruments considered. SMEs are underrepresented in NoEs. Their share in STRePs is relatively high.

[25] For comparison, the level of SME financial participation in early FP6 actions has been estimated by the Commission to be about thirteen percent for all instruments, and a little higher than that for IST. The level of SME participation was most favourable for STRePs and most unfavourable for NoEs. The pre-set target was of fifteen percent.

[26] The values of Coordinated Actions and Specific Support Actions are not reported,

Figure 13. Instrument participations by organisation size
IST Applications Network

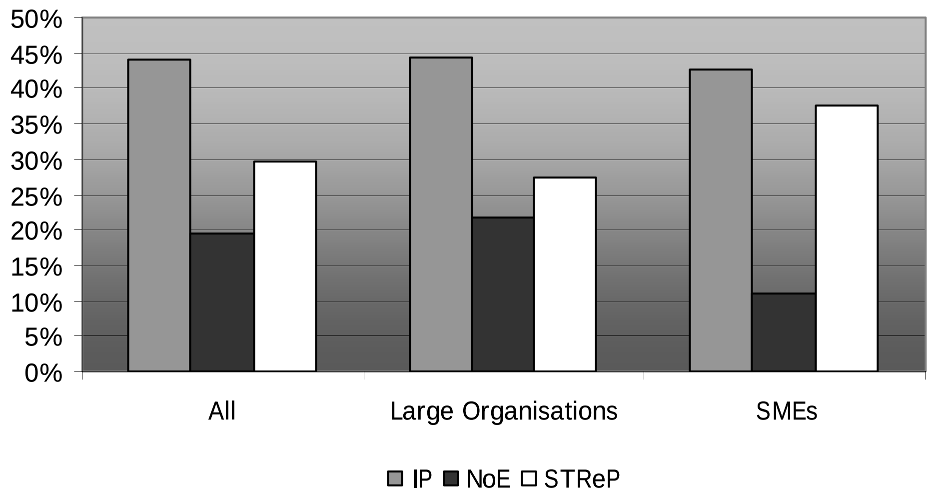
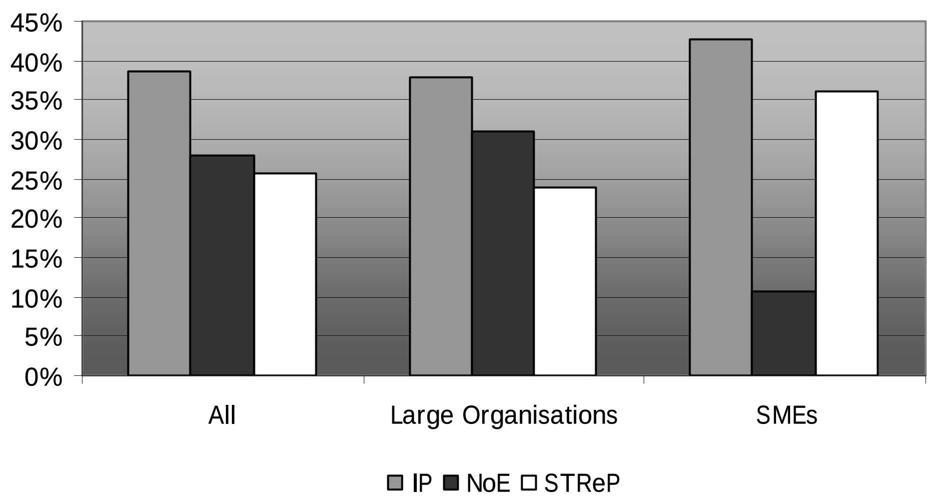


Figure 14. Instrument participations by organisation size
IST Development Network



Are the SMEs that participate in IST-RTD Programmes technologically active and innovative? We have considered a sample of SMEs participating in the examined IST Applications and IST Development programmes and a sample of SMEs that have applied for funding to those programmes but did not get selected. In addition, we have isolated European SMEs that own highly cited patents and controlled whether they were involved in IST-RTD projects.[27]

[27] A sample of 512 SMEs was created this way.

We find that SMEs participating in IST-RTD are significantly more technologically active (i.e. they patent more) than non-funded SMEs: around 25% of SMEs involved in the IST-RTD projects have at least one patent vs. 5% of the non-funded SMEs. We corroborated this finding with a survey of the National Contact Points in Member States. They were asked to rate the degree of innovativeness of a selected small sample of SMEs based in their respective countries. NCP answers also confirmed that SMEs involved in IST-RTD projects are more innovative than non-funded SMEs.

In addition, only a small fraction (5.4 percent) of European SMEs holding highly cited patents have been participating in IST-RTD projects.

We corroborated also this result taking into account a different list of companies, namely the most dynamic European SMEs.[28] It was found that only a small fraction (3.3 percent) has been participating in IST-RTD projects.

A relevant policy question arising from these findings relates to the possible barriers that limit the participation of many innovative SMEs in IST-RTD projects. Here, our analysis is necessarily speculative and mostly based upon interviews with industry representatives and existing studies. Besides the problems related to the often cumbersome and lengthy procedures associated with drafting, submitting and getting approval of project proposals and with the problematic issues arising from the definition of intellectual property rights, especially in relation to large and powerful organisations, the requirement of financial viability has been often claimed to be a major barrier inhibiting the participation of young innovative start-ups, lacking a sufficiently long financial track record. Adopting flexible and relatively fast procedures of project evaluation, especially in the case of projects coordinated by SMEs, and revising the rules defining the financial viability of contractors, shifting the emphasis from tangible assets to intellectual and knowledge related assets may consequently be seen as potentially useful policy steps for increasing the rate of participation of innovative SMEs in IST-RTD projects. On the side of incentives to participate in IST-RTD projects, a notable finding is the low rate of SMEs in NoEs as compared to IPs. This may be related to the long-term research objectives that seem to characterise NoEs and the relative lack of focus on specific products and processes. For most innovative SMEs growth perspectives are crucially linked to a short time-to-market introduction of new products and services. These characteristics, together with potential problems in the definition of intellectual property rights vis a vis larger organisations, may act to deter effective participation of smaller innovative companies in European research projects.

[28] Companies achieving the highest rates of growth during the period 2001-2004 in the relevant technological domains. In order to select these companies we have consulted the list of the Top500 fastest-growing European companies as reported by *Business Week* (October 24, 2005).

4. CONCLUSIONS, LESSONS AND CHALLENGES

Every emergent social network has a "scale-free" architecture, indicating 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 (locally or globally) 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 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 create networks that are subject to scale-free architectures. The implication for policy is straightforward: core organisations may provide the critical policy lever in the effort to approximate optimal solutions. Such organisations could play a pivotal role in steering the network toward desired socio-economic situations. For the Framework Programme, these translate into strengthening the scientific and technological bases of industry to encourage its international competitiveness and supporting other policies of the European Union.

We were asked to apply social network analysis to assess the nature and relative network positioning of core European organisations identified as "knowledge hubs". How are they positioned in the networks created through IST-RTD funding and 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 (IPs) and Networks of Excellence (NoEs) – 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? How does one use network methodology to get to the important question of the mobility of scientists and engineers across organizations and Member States in order to start to understand the effects on the networks of collaboration, dissemination and exploitation of knowledge?

A Hub was defined in this study as an organization with a large number of connections and/or an organization that is highly influential by playing the role of connector of parts of the network that would otherwise remain unconnected. Hubs have therefore an extremely important role to play in the examined IST-RTD programmes as they contribute towards the effective and fast diffusion of knowledge even to the most peripheral nodes of the resultant network.

We have used three large datasets of IST-RTD partnership networks (Thematic Areas 1, 2, 3; first two Calls of FP6), global partnership networks in IST, and knowledge networks (European patents and citations), supplemented with a set of public consultations and expert interviews, to reach a number of conclusions regarding the questions above.

4.1 MAIN FINDINGS

Summing up the main findings in this evaluation study, we found that the examined IST-RTD Programmes have very positive effects for the network connectivity of the European information and communication sector in terms of:

- **Attracting key actors to the European IST Knowledge Network**

IST-RTD Programmes attract Global Hubs. IST-RTD projects are able to attract Global Hubs whether these Hubs are based in Europe or not. More than half of the top 25 Global Hubs participate in the examined IST-RTD Programmes, a percentage that rises steeply if organisations are weighted according to their network ranking.

IST-RTD Programmes tend to attract the Hubs of Member States. 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. Probably due to the timing, the programmes include fewer such organisations from new Member States.

Different types of organisations play the role of Network Hubs in IST-RTD Programmes. There is a rather even distribution of Hubs among firms, higher education institutions and public research organisations in the examined IST-RTD programmes. Universities, however, play a higher role as Hubs compared to their overall participation rate in the IST Applications Network. Similarly, public research organisations are overrepresented as Hubs compared to their weight in terms of participation in the IST Development Network.

The importance of different types of organisations as Hubs differs across Instruments. The role of firms as Hubs in IST-RTD Networks increases significantly when Networks of Excellence (NoE) are excluded from the analysis. More than a half of the Hubs in the IST Applications Network and close to a half in the IST Development Network are, then, accounted for by private sector companies.

- ***Creating and strengthening 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 than IPs in that particular role.

- ***Generating and diffusing 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. IST-RTD Hubs also contribute to the dissemination of knowledge by playing a very significant role in the mobility of inventors among European IST organisations.

The evaluation analysis has also identified two other features of the European information and communication technology industry and of the IST-RTD programmes that deserve attention:

- ***Few European organisations are Top Global IST Network Hubs***

Relatively few European companies can be characterised as Hubs in the Global IST Network. A relatively small percentage of Global IST Network Hubs have been identified as organisations headquartered in Europe.

- ***Few of the highly technologically dynamic SMEs are part of the IST-RTD Programme***

IST-RTD involves innovative SMEs but there is still a lot of room for improvement. SMEs do not, and probably cannot, play central roles in the IST networks and therefore are not Hubs. Importantly, a large share of the most highly technologically dynamic SMEs does not participate in the IST-RTD programmes.

4.2. POLICY RECOMMENDATIONS

Hubs are important for providing the underlying linkage infrastructure that maintains vibrant IST network communities where knowledge is produced and diffused effectively. They also have distinct characteristics compared to other organisations in the IST network. The findings of this study lead to a few policy recommendations.

- *Promote the IST-RTD activities in the Research Framework Programme in order to maintain the connectivity and robustness of the European IST Network.*

The examined IST-RTD Thematic Area Programmes contribute effectively in attracting key actors in the European IST Network, in creating and strengthening network connectivity, and in nurturing the generation and diffusion of IST knowledge. All these are good reasons to recommend that the IST-RTD Programmes remain a core part of the European Framework Programme.

- *Make certain that Global Knowledge Hubs participate.*

IST-RTD Programmes must continue to attract Global Hubs and, especially, the Gatekeepers – that is, organisations that play the role of Hub both globally and locally in Europe. Such organisations are at the crossroads of IST-RTD projects and private initiative alliances around the world, thus putting in contact IST-RTD Programme participants with the broader global network of collaborations in information and communication technologies. Participation in knowledge networks is highly desired today because of the systemic nature of innovation and the inability of individual organisations to match all necessary capabilities, resources, and speed.

- *Expand the global reach of European IST-RTD Networks.*

Information and communication research and technology are undoubtedly international. Significantly more foreign companies are Hubs in the Global IST Network than European companies. The global reach of IST-RTD Programmes must be expanded by inviting foreign players to play an active role in the Programmes. This may require the extension of funding to foreign organisations. Local (European) concentration of funding can only produce European Knowledge Hubs, but not Global Knowledge Hubs.

- *Facilitate further development of existing European IST Hubs and their accession to highly ranking Hubs in the Global Network.*

Hubs are characterized by research and technological excellence, tend to be larger organisations with widespread resources, multi-talented teams and capabilities that span several fields, have significant organisational capabilities for network coordination, and hold strong market positions. These characteristics turn them into desirable partners and often place them into core positions in the network, implying superior capabilities both to reach information and resources in a timely manner and to control the network. It is not difficult to see why it is essential that a good number of Global Network Hubs are based in Europe.

Public policy aiming at creating Global Network Hubs should be multi-faceted. It should include all policy measures that nurture and support globally competitive organisations that combine scientific and technological excellence and critical mass.

- *Investigate the causes of limited participation by smaller, highly dynamic companies in the IST-RTD Programmes and ways to encourage their participation. Nurture new European IST Hubs.*

Policy must not lose sight of the importance of industrial renewal in fast-paced environments such as the IST environment. For the Framework Programme, this means maintaining low barriers to entry for smaller, newer organisations. Such barriers typically relate to the administrative burden of participation, stretching from the proposal stage to financing to coordinating the RTD project and reporting to the Commission. The associated cost may not attract SMEs to RTD projects.

The finding that there are still too few highly technologically dynamic SMEs participating in IST-RDT Programmes calls for the identification of excellent SMEs, their possible luring into the Framework Programe, and their support to eventually grow into effective Knowledge Hubs.

- *Maintain a balance of instruments, especially instruments with the characteristics of IPs and STRePs.*

Integrated Projects are very effective in linking global and local players. They provide the breadth and scale to attract the attention of Gatekeepers and other Global Hubs as well as IST-RTD Hubs. In other words, IPs are very important for connectivity. While IPs reduce fragmentation and help reach critical mass, STRePs are reported by industry to be well focused, functional, and easier to coordinate. They are thus often the instruments of choice for well-focused jobs and less intimidating (more manageable) for SMEs.

- *Be conscious about the resulting network structure when allocating IST-RTD resources. The desired network structure could conceivably be translated into a project selection criterion.*

The network structure will be affected by the overall objectives of the IST-RTD funding. One aspect of network structure is the type of participating organisations. Another aspect of network structure is the linkages among these organisations. This and earlier studies have indicated that the IST-RTD Network is a scale-free network, that is, one consisting of central organisations with many and/or critical linkages (Hubs) and more peripheral organisations (non-Hubs). Non-Hubs – a good number of which are SMEs – benefit from participation because by linking to a Hub they are close to the centre of the network.

A relevant policy question would be whether an Instrument (IP, NoE, STReP) should focus on links between Hubs or between Hubs and non-Hubs. If the objective of the network is the efficient flow of knowledge, then a mix of links between Hubs – so that knowledge from one part of the network flows easily to other parts – and links between Hubs and non-Hubs – so that knowledge actually flows into the peripheral areas of the network – would be preferred. This, in fact, raises the notion of "small world" structure which brings together these two linkage structures. If this is the underlying objective of the IST-RTD funding, policy makers may want to consider how the available Instruments might be constructed to maintain the desired kind of relationships. This consideration may provide yet another argument for Instrument balance advocated above.

Box 4 – On the desirable structure of networks

The analysis carried out in this evaluation, together with findings from previous studies, shows 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 all organisations in the IST-RTD network is relatively low and, at the same time, each organisation is embedded in a tightly connected cluster of other organisations. This structure is believed to be optimal 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, as emphasised in this evaluation, the IST-RTD network has also the property of being a scale-free network. This property refers to the fact that the network contains relatively few highly interconnected *Hubs*: the vast majority of nodes are weakly connected, and the connectedness ratio of the nodes remains the same whatever size the network has attained In addition to this, a further characteristic of the IST-RTD network (not always present in real world networks exhibiting scale-free properties) is that the Hubs are not only highly connected to other organisations, but are also highly interconnected to each other.

It is worth noting that a scale-free network is also a small-world network, while the opposite is not necessarily true. From this perspective, the emergence of a small-world topology in the IST-RTD network may therefore 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, as this report has already stressed, high transaction costs, as well as lack of resources, have been major factors refraining smaller firms and organisations from taking a coordinating role in IST projects. The only 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. In this way, the goal of achieving long-run cohesion and diffusion of knowledge seems 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).

We think this discussion is relevant for the design of new instruments aimed at increasing the effectiveness of the IST-RTD network. As this report has shown, the instruments used so far have been quite successful at creating a network structure which is effective in producing and disseminating knowledge at the RTD level. This has been achieved by means of policies that have strengthened links among Hubs, while at the same time 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 finding that several dynamic SMEs are not participating in IST-RTD projects may be seen as a warning signal in this direction. Both considerations suggest that, beside instruments aimed at further increasing linkages among Hubs (e.g. IPs) and among Hubs and non-Hubs organisations (e.g. NoEs), emphasis should be shifted towards more flexible and manageable instruments that allow smaller organisations to take a leading and coordinating role in IST projects. This does not imply that the current focus on Hubs should be changed. Rather, 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 also designed.

Appendix

Table A1. 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 characters are also Hubs in the Global Network (i.e. Gatekeepers).

Table A2. 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 characters are also Hubs in the Global Network (i.e. Gatekeepers).