ICT Network Impact on structuring a competitive ERA

Final Report

February 2012

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Executive Summary

The core objective of this study was to develop and implement a methodological framework for assessing the effectiveness of ICT-RTD networks formed in Framework Programme Six (FP6) and Framework Programme Seven (FP7) in supporting the competitiveness of the European Research Area (ERA). More specifically, the study analysed the *networks* of organizations[1] engaged in FP funded pre-competitive research co-operation. The basic building blocks of the network are a set of organizations and the ties that link them. The set of organizations included the 7286 distinct organizations that participated in the collaborative ICT-RTD projects funded by the DG INFSO in FP6 and FP7 [2].

The information on participation in FP6 and FP7 has been merged with information on privately funded R&D strategic alliances in comparable ICT fields, using the SDC Thomson database. Finally, for all organizations involved in these collaborative projects, we collected data on the patenting activity at the European Patent Office (EPO).

Using this information, the study has undertaken two types of analyses:

A. First, we examined to what extent the European FPs have been able to attract
   - (i) leading national research organisations
   - (ii) highly dynamic and innovative small and medium-sized enterprises (SMEs)
   - (iii) technology exploiters and explorers.

B. Second, we adopted the techniques and methods of social network analysis to conduct a systematic analysis of the structural properties of various kinds of networks and of the positioning of European organisations in such networks.

The present study builds upon a series of earlier studies carried out for DG INFSO. Some of the findings reported herein confirm patterns already outlined with earlier data, thereby

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[1] The concept of an *organization* in this context needs clarification. DG INFSO data do not allow unequivocal identification of the organizational *sub-units* involved in each project. Especially for large public research organizations and large companies different departments, institutes and research teams are involved in different projects. Since it is impossible to differentiate on the basis of the raw data the various units and all of them have been collapsed into the *parent* organization to whom they belong.

2 *up to August 2010*

providing evidence of continuity in the impact of FPs. Additional findings shed new light on the fabric of the collaboration network emerging from DG INFSO funded collaborative projects.

The following key findings are further explained in the next section and followed by a set of recommendations:

1. The fact that leading national research organisations of the new Member States play a relatively minor role ***is not*** a result of the Programme design. The fact that highly dynamic SME's are underrepresented in the FP's however ***is*** a result of the Programme design;
2. Highly dynamic SME's are critical for the innovation potential of the FP networks. Where these SME's participate they generally aim for full control of a project and relatively small consortia;
3. The FP evaluation process tends to filter out smaller innovators (pioneers);
4. There is a low persistency in industry participation in general, and a high inertia in network evolution among the frequent participants;
5. The (newly identified) connector organisations keep communities (sub groups within networks) 'alive', dynamic and innovative by connecting communities and injecting 'community foreign' knowledge;
6. ICT RTD networks are mostly driven by traditional players as (large) public research organisations (hubs) which may not be appropriate to sufficiently support the shifting paradigm towards exploitation and innovation;
7. ICT networks are resilient; although removing IP's seriously reduces the size of the networks, it will not destroy them. Removal of STReP's keeps the connectedness of network as is, but it throws small players out of the network. IP and STREP are in a sense substitutes of each other from a network perspective. Removal of NoE's will only have a marginal effect on the networks.

ANALYTICAL INSIGHTS

Participation of leading national research organizations (LNRO) in European ICT RTD networks

The design of FP6 and FP7 has been able to attract the leading research organisations both from older and, with some exceptions, also from new Member States. In this respect, the FP is achieving one of its key objectives, namely that of strengthening the cohesion within the European Union. At the same time, LNROs from earlier Member States tend to dominate in terms of number of participations and projects co-ordinated. Such an asymmetry may be more associated with differences in the scale and scope of available resources than to any aspect related to the design of the FP. The leading research organisations are typically large organisations (universities and public research organisations) which operate labs and research units with resources that enable them to sustain high levels of cross-institutional co-operation and to take the leadership role in projects. The scale and scope of resources available to such organisations in older Member States, especially the larger countries, is typically larger and broader than to organisations located in new Member States.

The future design of ICT RTD activities should take as its starting point the effectiveness of existing instruments in attracting the leading research actors in the European ICT-RTD Network. Leading (and a fortiori more marginal) actors from new Member States states may experience difficulties in entering into the network in a stable and central way.

Participation of Highly Dynamic SME's in FPs

In a fast-paced environment such as ICT, new products and services are often introduced by entrepreneurial new companies. They are often better placed to undertake the process of technology transfer from research results to marketable goods and services. Our findings show that the existing programmes have been relatively less successful at attracting these dynamic actors than they have been at attracting incumbent and established players. Although this result is not entirely new, it is quite striking that it is highly robust with respect to very different definitions of what constitutes an innovative and highly dynamic SME. Understanding the reasons that prevent some of those companies from participating in the FP should thus be given a top place in the research agenda. Removing the barriers and the obstacles to the participation of these companies, typically related to the administrative burden of participation, stretching from the proposal stage to financing, coordinating the RTD project and reporting to the Commission, sounds like an obvious implication of this finding.

Yet, it is likely that there is more than that. In the first place, our findings show that those few innovative and dynamic SMEs that chose to participate almost invariably took a role as project co-ordinators, thereby making explicit the purpose of keeping control over the direction of the research undertaken. Second, they were almost exclusively involved in collaborative projects with a relatively low number of participants, thereby ensuring a more focused orientation of the research. Finally, as discussed below, the same design of the FP that ensures the participation of large and leading organisations and the achievement of the cohesion objectives may come at the cost of attracting new innovative companies. The point here is that large established players (most of them universities and large PROs and firms) play the function of hubs, thereby representing the entry point into the network for smaller new entities. To the extent that the knowledge, capabilities and objectives of such big players are not aligned with those of smaller new actors, a sort of adverse selection may take place, according to which relatively less capable and more aligned entities apply and are granted access to the network. In addition, asymmetric information among parties, which is typical in those contexts, is just likely to exacerbate the problem.

The future design of ICT RTD activities should take into account the potential difficulties of smaller but fast-growing and innovative SMEs to participate. Small and focused collaborative projects are likely to be the most suitable approach to elicit the involvement of these companies.

Role and participation of technology exploiters and pioneers

FP6 and FP7 have been highly effective in attracting leading technology *exploiters* and innovative technology *brokers*. While the former organizations focus their research activities towards the exploitation of opportunities in relatively mature fields, the latter do research in new fields and provide access (broker) to those fields for other organisations. Both types of actors tend to be found among relatively large and well established firms. At the same time, the selection process into the FPs tends to filter and leave out what we have called technology *pioneers* and *isolates*. This group includes heterogeneous organisations, typically smaller innovators undertaking research in unexplored fields. Whereas the majority of them are likely to work on less original and fertile projects, some are pioneers, namely they are engaged on exploratory but promising new ideas, not yet seized by other and larger companies.

Designing appropriate instruments to identify, select and attract those pioneer innovators pursuing the most promising new ideas seems to be an important challenge for the future designs of IST-RTD collaborative activities. As argued above, the existing instruments might generate a sort of adverse selection process by which precisely those firms less aligned with the interests of hub organisations are excluded from the participation in the FP. At the same time, identifying ex-ante the most promising innovators is a process that implies high degrees of risk and uncertainty.

Designing appropriate instruments to identify, select and attract pioneer innovators pursuing most promising new ideas should remain a core challenge for future designs of RTD collaborative activities.

The profile of FP participants and of the process of formation and deletion (i.e. not repetition) of collaborative ties

The study has undertaken a careful analysis of the process by which collaborative ties among organizations are formed and repeated. The available evidence suggests a picture of the evolution of the FP network, in which a core of established organisations (mostly large universities and public research organisations) persistently participate across the different FPs, accounting for the vast majority of the ties established in each FP. On the other hand, lower persistency in the participation rates characterise the industry actors, especially small and medium sized companies. Moreover, a relatively large fraction of all ties established in a FP involves pairs of organisations that have been already collaborating in the previous FP. This suggests a rather high degree of *inertia* in the patterns of collaboration.

The design of programmes should address the low persistency in participation by industrial actors – especially SMEs - and the inertial tendencies in collaboration among frequent participants.

The structural properties of the FP network

The results of our thorough social network analysis indicate that both the FP6 and the FP7 have generated a network which has the properties of a so-called *small-world network*. First, any two organizations in the network are separated by a very short chain of other organizations. Second, collaborating organizations form *locally cohesive* groups (cliques) in which an organization's partners are also partners with each other.

This type of pattern is actually not new and it has been found over and over again across successive FPs. In addition to this, however, we have carried out a novel kind of analysis aimed at partitioning the network into its constitutive elements (*communities)*. Communities can be defined as subsets (clusters) of nodes such that (i) within each community there are many ties among organisations, but (ii) between communities there are fewer ties. After identifying the communities that constitute the network, we have classified nodes according to the position they occupy. The FP network is characterised by a three-tier structure consisting of the following types of organizations:

1) *Hubs*: extremely connected organisations which tightly identify with a well-defined community. Hubs represent around 3% of all organisations participating in the FPs. Their important role is to orchestrate collaboration among partners which do not have the scale and capabilities to play a co-ordination role,
2) *Connectors*: organizations often with a lower number of ties overall but with their links *distributed across* different communities. They represent more than one-third of all organizations participating in the FP. They are a middle-tier type of organisations and play a critical role in transferring and transmitting knowledge from one side of the network to the other.
3) *Peripherals*: least connected organizations. Their participation in the FP typically takes place through joining a consortium co-ordinated by a Hub organisation. Peripheral organizations represent the bulk of all organisations in the FP.

What type of message emerges from these findings? Our interpretation is that the existing fabric of the FP network may favour the achievement of some objectives, but it may impair that of others. Small-world networks and Hubs are known to facilitate knowledge diffusion and the cumulative building up of capabilities. Moreover, such networks tend to be also highly resilient: the lines of communication and co-ordination are not affected by the fact that some organizations (except hubs) drop from the network.

At the same time, a network such as the one emerging from the IST-RTD projects may be exposed to two types of problems. On the one hand, there may be a risk of technological lock-in and inertia. Highly cohesive cliques, like the ones existing in a small-world network, orchestrated by large organisations favours the building up of local capabilities, but at the cost of generating a lot of redundancy. In those cliques, the knowledge, methods, approaches and solutions to problems tend to converge and become more and more similar across actors. The search for novelty and exploration may thus be hindered, as our analysis has shown with respect to the inclusion of highly dynamic and innovative SMEs. On the other hand, the existence of *Hubs*, which orchestrate the collaboration of peripheral agents, may create a barrier to the inclusion in the network of new players. Those hub organizations play the role of filters into the network. To the extent that new players are carrying knowledge and objectives, which are not aligned with those of Hubs, their participation in the network may be precluded.

The design of programmes should consider the benefits of stability through Hubs. However, policies should also be considered that nurture the emergence of new Hubs from the ranks of those organisations that we have called above as Connectors.

The characteristics and roles of network hubs

Who are the Hubs in the IST-RTD network? A good majority of ICT RTD Network hubs are public research and teaching organizations. This corroborates with a long series of earlier findings in evaluating the Framework Programmes over the years. Respondents to questionnaires have time and again stressed benefits from participation as being primarily intangible and indirect (networking, information gathering, capability building) rather than direct benefits in terms of products and process innovations. This is not to say that the Programme is not useful or well focused. In fact the Programme for a long time since its inception was considered an instrument to promote pre-competitive research. It is in more recent years that emphasis in the political realm has gradually shifted towards application / innovation. If the expectations for the Programme are changing, then it may not yet be adequately reflected in the composition of research consortia.

The IST RTD Network is deeply influenced by public research and teaching organizations, which is in line with the pre competitive nature of the FP's. If the FP policy trend keeps shifting towards exploitation and innovation, this shift needs to be translated into instruments enabling more innovation-oriented organisations to take a hub role.

As a partial confirmation of this hypothesis, the share of hubs claimed by European organizations drops significantly when one moves from the IST-RTD Network to the Patent Citation and Patent Co-citation Networks. The drop-off is not surprising in light of the argument in the previous paragraph regarding the heavy presence of higher education and public research organizations as IST-RTD Network hubs. In contrast, patent networks' hubs are dominated by private sector companies.

The Role of Different Funding Instruments in Bridging Organizations

In order to assess the role played by different funding instruments, we have performed a sensitivity analysis aimed at assessing the resilience of the FP network with respect to removing (without replacing) a given funding instrument. Results of this analysis show that:

a) The FP network is highly robust with respect to the removal of single funding instruments. In particular, the extent of connectivity and the small-world properties remain fairly unchanged even if as big chunk of the FP as Integrated Projects are eliminated.
b) However, different instruments play different roles. In terms of organizations that would become isolates, without any network access, STReP is the instrument with the highest impact. Around two-fifth of all FP participants would be expelled from the network without it. STRePs are thus very important in terms of bringing new participants (more peripheral) into the network. At the other hand of the spectrum, NOEs is the least prominent instrument in terms of structural effects onto the network if removed.

The ICT-RTD network will survive shocks as big as the removal of single most important funding instruments like IPs or STRePs. Nevertheless, the loss of a big instrument will result in the loss of large numbers of participating organizations. In the case of STRePs more than any other, new, more peripheral participants will be removed.

In our view, there are two sides to this story. One the one hand, the IST-RTD network displays a high degree of resilience, a positive property signalling the ability of the network to withstand shocks. On the other hand, the very fact that the extent of connectivity and the basic properties of the network are not affected fatally by the removal of important funding instruments also signals the existence of significant overlap of participants among instruments. More intuitively, the removal of a core instrument such as IP does not have a devastating effect on the connectedness between organisations because besides that instrument they are simultaneously linked by other instruments such as STRePs and NoEs. The most real effect of funding instruments' removal is on the inclusion of large numbers of organisations in the network's periphery.

The above is not to trivialize the role of IPs and STRePs. Removal or either funding instrument results into deep cuts in terms of participating organizations. If anything, the influence of IPs is extensive but somewhat more concentrated in terms of organization categories compared to the influence of STRePs which comes across all categories. For instance, elimination of IPs in the IST-RTD Network affects extensively two of the three Hub categories and also seriously several non-hub categories of participants. The elimination of STRePs which cuts deep across all participant categories and affects heavily peripheral organizations.

IPs and STRePs provide the backbone of the examined networks and must continue receiving significant attention by program managers and policy makers.

Emphatically shown in this study, the ICT RTD Network of the past two Framework Programmes is deeply influenced by a small number of organizations. Two groups of hub organizations amounting just to 3% of all network participants hold the key in keeping the network together as we know it. A third group of non-hub organizations is large enough

(38% of all participating organizations) with significant enough share of activity (linkages) to provide a base for the network. Absent these three groups of organizations, the network collapses.

The most highly connected Hubs have always attracted attention in policy circles. So has the large group of organizations in the periphery of the Network. We believe the story of the middle ground – non-hub, inter-module connector organizations – is new. These organizations deserve much more attention than they have received till now as they provide critical connections among network communities and, as said earlier, could also provide a set of new Hubs for network renewal.

Two categories of ICT RTD Network participants deserve special attention by policy decision-makers in order to strengthen their position and ensure their role. The first includes the most connected hub organizations. The second includes a large number of relatively unglamorous non-hub organizations (connectors) with high connectivity across network modules.

Recommendations – Towards Horizon 2020

While at the time of this study Horizon 2020 did not exist, the underlying realities of both are obviously identical. Therefore, the recommendations for future programming in the following section address central challenges of H2020, even though they were not drafted in light of the new Programme.

Horizon 2020 has three main priorities: (a) excellent science; (b) industrial leadership and innovation; (c) societal challenges. This study is clearly relevant as it deals with the most central infrastructural industrial technology (ICT) and analyses connectivity which is directly related to the production and dissemination of research results. There are three major dimensions in the study that impact future programming:

- **Participation of industry players**: The analysis fully supports the importance of extending the involvement in the networks of industrial partners, in general, and SME's, in particular. H2020 should be aiming at including highly innovative, fast growing SME's, and keeping them and other industry in the common collaborative programmes over time in order to optimise the return on investment in terms of innovation.
- **Instruments and types of organisations:** both STReP and IP type instruments are highly relevant for the effectiveness, integrity and consistency of the networks. Two types of organisations are particularly important in this respect and need special attention: Hubs (with many connections within a group or community) and Connectors (with connections across groups or communities).
- **Innovation and exploitation:** The study fully supports the importance of an integrated approach to research and innovation objectives. It is important to identify and include the most exploration-oriented organizations, policies must be devel-

oped to better translate research results into applications, and the instruments must be aligned to better leverage the results of R&D.

The following 5 key Policy-oriented recommendations can de derived from the analytical insights relevant to the priorities of the new Programme for excellent science, industrial leadership, and innovation:

Recommendation 1: *The identification and inclusion of the most explorative innovators can be enhanced*. IST RTD networks already feature the leading research actors across Europe. This success does not extend to the most fast-growing and innovative SMEs of the continent.

Recommendation 2: *The design of FPs should address the low persistency in participation by small industry players and should push for a greater rate of recombination of research partners.* The IST RTD network has evolved around a core of established organisations (mostly large universities and public research organisations) that persistently participate across successive FPs. On the other hand, low persistency in the participation rates characterise the industry actors, especially small and medium sized companies. Moreover, a relatively large fraction of all ties established in a FP involves pairs of organisations that have been already collaborating in the previous FP.

Recommendation 3: *Highly connected organizations, whether hubs or non-hubs, deserve special attention by policy decision-makers.* By connecting outside their immediate "neighbourhoods" they will also contribute to alleviating the tendency of stable partnering. The most connected organizations in the IST RTD Network are also the most effective in creating and disseminating knowledge. A second category of highly connected non-hub organizations – extensively connected outside their "community" – are also emerging as very important in sustaining the Network.

Recommendation 4: *Maintain the distributive structure of the IST RTD Network. On the whole, this is good for inclusion and for diversification. That being said, the current composition of the Network – heavy in public research and teaching organizations – does not align well with a changing policy mandate for increased innovative application.* This skewed participation is partly the reason why the benefits from the strong IST RTD Network among European organizations do not translate into equivalently strong positioning in patent-centric networks. Even though participants (especially private companies) describe significant impact on innovation, this comes mainly indirectly. Directly commercialisable output has not been a core objective of Framework Programmes. And this seems to be changing.

Recommendation 5: *IPs and STRePs provide the backbone of the examined networks and must continue receiving significant attention by program managers and policy makers.* While the IST RTD network can survive shocks as big as the removal of single most important funding instruments like these, the loss of a big instrument like that will result in the loss of large numbers of participating organizations. In the case of STRePs the loss will include a lot of the more peripheral network participants.

In addition to the recommendations above oriented towards principles for strategic planning and designing future ICT programmes and funding instruments, our results underwrite advice to Member States in terms of:

- renewed effort to promote the Programme among their most exploration-innovative SME's
- redoubled effort to place industry at the core hub positions in the ICT-RTD network
- assistance in translating research results into inventions and innovations
- increased attention to the invisible middle of participating organizations many of which, even though non-hubs in their immediate network community, appear to play important role in linking across communities.

It is the empirical definition of such communities where we believe a useful next step in network analysis can come. It should be combined with the identification and characterization of this middle-ground organizations (inter-module connectors) as compared to the most highly connected Hub organizations.

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1 Introduction and background

1.1 Background

A workshop organized by DG INFSO and DG Research on March 5, 2009, reflected on the state-of-the-art in using network methodologies for the evaluation of R&D programmes and identified strengths and remaining challenges.[i] The overriding consensus was that we urgently need a much better understanding of the 21st century innovation 'system' and its complex causal mechanisms as a guide to visualizing new systemic indicators and metrics for evaluation purposes. This goes hand in hand with improving our understanding of the process by which research contributes to innovation and change. Network analysis was argued to be a useful research tool in so far as it provides a narrative of the interactions between players. The results of several studies carried out in the past few years under the sponsorship of the two organizing DGs have opened new pathways in formalizing network analysis and interpreting the results for informing science, technology and innovation policy.[ii]

The core objective of the present study was to develop and test methodological frameworks for assessing the effectiveness of ICT networks formed in FP6 and FP7 in supporting the ERA.

1.2 Data sources

Three major sources of data have been combined for this project. First, we collected data on the participation in the FP6 and FP7 in the ICT and IST thematic priorities, using the CORDIS database[iii]. This information was then merged with information on privately funded R&D strategic alliances in comparable thematic fields, using the SDC Thomson database. Finally, for all organizations involved in these collaborative projects, we collected data on the patenting activity at the European Patent Office.

The data set built in this way contains 7286 organizations, which have participated in the FP6 and FP7. Of them, 1975 organizations have also patented at the EPO in ICT-related technologies (i.e. the intersection between FP and the EPO is around 27%). On the other hand, only 220 organizations among those involved in the FP projects have been also involved in privately funded R&D alliances.

The data set used for this study presents both strengths and weaknesses that should be taken into account in the interpretation of results and in the design of future studies. As far as the strengths are concerned, the database allowed us to capture the research interactions among organizations at different levels, i.e. pre-competitive research funded by the EU, downstream knowledge generation and research co-operation among firms. In addition to this, patent data permit a rather fine-grained analysis of knowledge flows among organizations, through the analysis of patent citations and mobility of inventors.

At the same time, one should not neglect that the data used in this study entail some weaknesses. First, due to the way in which they are collected, the data on participation in the FP projects hardly allow to identify the organizational units involved in each project. Especially, for large public research organizations, such as CNRS or FhG, large Universities, such as ETH Zurich, and also large companies, such as Philips or Siemens, different departments, institutes and, more generally, research teams are involved in different projects. Yet, the raw data provided in the CORDIS database are such that it is extremely difficult to discriminate among these various units and all of them are collapsed into the "umbrella" parent organization to whom they belong. This is a major limitation for carrying out the kind of network analysis, which is at the core of this study (see below).

Second, patent data present some limitations as indicators of innovation output, which are quite well known. In this respect, however, it should be remarked that our use of patent data was not related to their nature as indicators of innovation output. Rather, we used them as relational data, namely to capture various aspects of the knowledge exchange process taking place among different organizations.

Third, the low intersection between FP participants and SDC Thomson is not particularly satisfactory. It probably signals a bias of the SDC Thomson database towards alliances involving US companies. In other words, it is possible that our data set underestimates the extent of privately funded R&D alliances, which involve European organisations.

1.3 Study tasks

Using the information described above, the study has undertaken two types of analyses.

- First, we examined to what extent the European FPs have been able to attract (i) leading national research organisations, (ii) highly dynamic and innovative SMEs and (iii) technological leaders, brokers, followers and isolates.
- Second, we adopted the techniques and methods of social network analysis and we undertook a systematic analysis of the structural properties of the various kinds of networks and of the positioning of European organisations in such networks. In particular, we examined the role of ICT "hub" organizations in the creation and distribution of knowledge within the networks to understand better the contribution of different funding instruments in creating/sustaining inter-organizational collaboration.

In what follows, we briefly report on the methodology used for each task, the main results and the main policy insights that can be derived from the analysis.

2 Participation in the ICT RTD network

2.1 Participation of Leading National Research Organizations (LNRO)

The study required assessing the extent of participation of *leading national research organizations* (LNRO) in European ICT RTD networks.

2.1.1 Methodology

In the absence of a univocal definition, we defined LNRO as comprising those *scientific research organizations* that, in each country, have a "prominent" role in the production of *published* scientific knowledge in the field of ICT. To measure the scientific production of these organizations, we used scientific articles published in journals relevant for the ICT field in the Thompson-ISI Science Citation Index (SCI) database[iv]. Consequently, we analyzed all articles published in the period 2004-2008 in the 175 most important scientific journals relevant for these fields and we assigned each scientific article to the respective organisation according to the affiliation of the author(s). Moreover, we dropped from the sample all articles authored by private companies and by organizations from non-EU countries. For the remaining articles, we standardized the names of the affiliations and we matched the data with the names of participants in FP projects.

Finally, for each country, we ranked by number of publications, separately, universities and public research organisations (PROs). *Leading* national research organizations have been defined, for each country, as the top 1%, 5% and 10% universities and PROs in terms of number of scientific articles in the ICT fields[v].

2.1.2 Strengths and weakness of methodology

As argued above, the concept of leading research organisation is quite ambiguous and it may be operationalized in different ways. The approach adopted here puts emphasis upon the role of *scientific* leadership that such an organisation should play. In addition, our methodology is based upon a database, which collects articles published in the most important international peer-reviewed scientific journals. At the same time, it must be emphasised that being *leading* in basic research is something different from being *leading* in applied science or technology. As long as a national research organization is able to play a role as a leader in the industry *without* publishing a substantial amount of its research output, our analysis might lead to a misleading identification of the "true" LNROs. Although this may happen occasionally, we believe that those cases are sufficiently rare. Moreover, even assuming that published scientific output constitutes a sufficiently valid proxy of (research) leadership, a further limitation of our methodology is represented by the use of Thomson Reuters's Science Citation Index (SCI) as a source of information. The point is that a rather significant share of ICT research publications are disseminated through conference proceedings papers, which are collected in different databases than SCI. Despite all these limitations, we are rather confident that they should not affect the main insights emerging from our analysis. Moreover, the study comprises an explicit analysis of the participation in the FPs of *technological* leading organisations (see below), so that one of the critical weaknesses discussed above is properly addressed.

2.1.3 Findings and policy insights

Evidence shows that all universities in the top 10% participate in the FPs, with the only exception of the UK, in which two universities out of ten are not involved, and Bulgaria, Estonia, Luxembourg and Malta. The leading universities participate in a large number of projects. On average the top 1% leading universities participate in 52 projects, while the top 10% participate in 45 projects. In the vast majority of cases, the leading universities that participate in the FPs do so by taking a co-ordination (leading) role. On average the top 1% universities are co-ordinators in 80% of the projects in which they participate, while the top 10% are co-ordinators in slightly less than 77% of projects.

As far as the participation of PROs is concerned, all PROs in the top 1% are involved in the FPs with the exception of Ireland. Moreover, for a few small countries- Estonia, Luxembourg, Latvia and Malta- we could not find any leading PROs in the ICT fields. The fraction of leading PROs participating in the FPs slightly decreases if one takes the top 10% organizations. The reduction in participation rates concerns mostly large countries, such as UK and France, but also some smaller countries, such as Denmark and Belgium. Yet, participation rates remain in general very high: on average 83% of EU leading PROs in the ICT field have been involved in FPs. Leading PROs tend to participate into a lower number of FP projects than leading universities. The average number of projects is 59 for the top 1% PROs and 26 for the top 10%. In spite of a lower participation rate, leading PROs that participate tend to take the role of project co-ordinators. On average, they co-ordinate 78% of the projects in which they take part for the top 1%, and 76% for the top 10%.

Finally, a comparison between EU15 and EU27 shows that leading national universities tend to be larger and to participate in a larger number of projects in the EU15 than in the EU27 as a whole. Quite interestingly, this pattern seems to reverse if we look at the leading national PROs.

Table 1: Participation of leading national research organisations (top 10%)

	Number of leading universities	of which % participating in FPs	Number of FP projects	of which % co-ordinated	Number of ICT publications
EU27	3.0	95.0	45.1	76.8	336.9
	(3.3)	(20.2)	(28.4)	(24.0)	(254.9)
EU15	4.4	98.6	52.9	83.6	501.1
	(3.8)	(5.2)	(23.3)	(5.1)	(228.0)
	Number of leading PROs	**of which % participating in FPs**	**Number of FP projects**	**of which % co-ordinated**	**Number of ICT publications**
EU27	4.0	83.0	25.8	76.2	163.0
	(5.2)	(20.0)	(21.0)	(16.4)	(122.6)
EU15	5.7	71.2	28.4	74.5	153.9
	(6.0)	(18.3)	(23.1)	(17.1)	(120.1)

Average values; std. deviations in brackets.

Overall, these results indicate that EU *leading* universities and PROs present a very high propensity to participate in the FPs, by participating in a relatively large number of projects, and taking a role of co-ordination in those projects. From a policy evaluation perspective, these results simply indicate that the current design of FP projects and funding instruments has been able to attract the vast majority of the leading national public actors in all member states, both within founding members and among new member states.

Analytical Insight: The examined ICT-RTD programmes have contributed effectively in attracting the leading research organisations, both from the founding and from the new member states. These are typically large organisations (universities and public research organisations (PROs)), which operate labs and research units with resources that enable them to sustain high levels of cross-institutional co-operation and to take the leadership role in projects. For this reason, the existing programmes should be maintained. At the same time, it should be also carefully considered the extent to which the existing design is preventing the access to the funding and collaboration opportunities for smaller actors, especially small and medium sized companies.

***Conclusion:** The future design of ICT RTD activities should take the effectiveness of existing instruments in attracting the leading research actors in the European ICT Network as its starting point.*

2.2 Participation of highly dynamic and innovative SMEs

The service study required also assessing the extent of participation in FPs of *highly dynamic and innovative SMEs*.

2.2.1 Methodology

Our data about innovative and dynamic small and medium size enterprises in the ICT industry are taken from four editions of the well know ranking "Deloitte Technology Fast 500 EMEA", an annual publication by Deloitte Touche Tohmatsu Limited (hereinafter Deloitte), the auditing and consulting company. We considered the most recent publicly available lists, those from 2006 to 2009 (inclusive). For this study, we focused our attention on firms active in telecommunications and networking, computers and peripherals, Internet, semiconductors, components and electronics, media and entertainment, software. In addition to this, we restricted the analysis to companies having their headquarter within the European Union. It is important to remark that inclusion in the Deloitte annual ranking is determined through nominations, public company research and Deloitte Technology Fast 50 country programs. To be eligible, a firm must be a technology company, it must have base-year operating revenues of at least €50,000 and a current year operating revenues of at least €800,000, and it must be in business a minimum of 5 years[vi]. Our final sample comprises 830 fast growing SMEs.

2.2.2 Strengths and weakness of methodology

The methodology adopted here to identify highly dynamic and innovative SMEs has obviously both advantages and limitations. On the one hand, the eligibility criteria used by Deloitte ensures that the sample contains truly innovative and dynamic European SMEs[vii]. On the other hand, the restriction that the firm must be in business for a minimum of 5 years implies that the sample is likely to exclude newly formed technology based firms (or technology based firms that have not survived until then). In other words, the sample is likely to contain only new firms that have been so successful to overcome the liability of newness and survive (and grow) for a period of at least five years. Of course, the sample examined here is not a random one. Yet, it is important to clarify that the objective of the exercise was to assess to what extent highly innovative and dynamic SMEs are participating in the FPs. Hence, *by definition*, the sample to be examined is a biased one, as highly innovative and dynamic SMEs are likely to be found in the right tail of the performance distribution of SMEs.

In order to test the robustness of our findings, we have adopted a different definition of highly dynamic and innovative SMEs, by exploiting information coming from the Industrial R&D Investment Scoreboard, published annually by the European Commission. The Scoreboard reports information on the 1000 EU companies investing the largest sums in R&D in the last reporting year. The *Scoreboard* includes data on R&D investments along with other economic and financial data from the last four financial years. The data for the

Scoreboard are taken from companies' publicly available audited accounts. Here, we examined the 2008 edition of the Scoreboard. The interesting aspect of this report is that R&D data refer both to very large and to small and medium sized firms[viii]. From the 2008 edition of the R&D Scoreboard, we selected all companies with less than 500 employees and active in sectors broadly related to the ICT field. The threshold adopted by the European Commission to define a firm as an SME is 250 employees. We used a larger threshold to ensure a larger sample of potential participants.

2.2.3 Findings and policy insights

Out of 830 fast-growing SMEs, we could find participation in FPs only for 36 of them, namely slightly less than 5%. These companies participated in a low number of projects: 39 in the FP6 and 19 in the FP7. On average, they participated in 1.61 projects, which indicates that most of these companies tend to participate in only one project. It is worth noting that the average number of projects per organisation is 3.9 if one considers the whole population of participants.

As far as the type of funding instrument is concerned, the vast majority of these firms participated either in Specific Targeted Research Project (49% of all projects in FP6) or Integrated Projects (44% of all projects in FP6). If one takes the whole population of participants, the same fractions are, respectively 38% and 35%. As far as the 7th FP is concerned, almost all projects in which these companies have participated are Collaborative Projects (18 out of 19).

We believe it is remarkable that in slightly less than 90% of their 58 projects, such companies acted as main contractors and in just 8 cases they are only participants. This indicates that, in spite of being relatively small, these firms have the capabilities to manage and coordinate relatively large project consortia It is also worth noting that these companies have 78 EP patents, though only 11 of them patented. This suggests that patent data may be a rather imprecise indicator of the extent of innovativeness of SMEs, especially in ICT fields.

Finally, it is also quite interesting to observe that 5 out of 36 participating firms (14%) are from new member states (SMEs from new member states are 83 out 830, i.e. 10% in the whole population of highly dynamic and innovative SMEs).

As argued above, we tested the robustness of these results by looking at a different sample, i.e. high R&D-intensive SMEs. The sample includes 95 R&D intensive ICT firms, whose average size in terms of number of employees is 251. We could find participation in the FPs for only 12 of them, i.e. around 13%. Considering that the firms listed in the R&D Scoreboard are larger and older than the firms listed in the Deloitte ranking, the results are not too dissimilar. Thus, despite all the caveats, we are quite confident that the findings emerging from our analysis are rather robust. Remarkably, they are also consistent with a previous study carried out for the DG INFSO showing among SMEs holding highly-cited patents in the ICT fields around 5% are involved in the FP.

It is important to remark that the results reported in this section should not be interpreted as evidence that SMEs participating in the FPs are *not* dynamic and innovative. Several recent studies suggest that FPs are able to attract highly innovative European companies and institutions. The clear message emerging from this study is that a large fraction of highly dynamic and innovative SMEs *do not* participate in the FPs. Understanding the reasons that prevent these companies from engaging in the collaboration opportunities offered by the FPs is beyond the scope of this study. Yet, we do suggest that such an understanding is crucial for the future design of policy instruments.

Analytical insight*:* In a fast-paced environment such as ICT, new products and services are often introduced by entrepreneurial new companies. They are often the actors, which are better placed to undertake the process of technology transfer from the results of projects to marketable goods and services. The existing programmes have been relatively less successful at attracting these dynamic actors than they have been at attractive incumbent and established players. It is urgent that the barriers and the obstacles to the participation of these companies are removed. 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. Specific instruments tailored around the needs and the resources available to these companies must be designed. At the same time, it should be always kept in mind that identifying truly excellent SMEs and eliciting their participation in the FP is a difficult and uncertain task, given the high levels of information asymmetry.

***Conclusion**: The future design of ICT RTD activities should take into account the potential difficulties of smaller, but fast-growing and innovative SMEs.*

2.3 Participation of technological leaders and brokers

The third component in the analysis of participation in the FPs was analysis of the extent to which the FPs have been effective in attracting two important types of innovative companies: technology leaders and technology brokers. The former can be defined as those companies that, within a broad technology field, are engaged in the exploitation of a well-established technological trajectory and whose innovative output represents a source of valuable new ideas for other organisations. The latter can be defined as those companies that are engaged in the exploration of new directions of research and whose innovative output opens up new opportunities for many other organisations.

2.3.1 Methodology

Our approach is based upon a methodology developed by Podolny and Stuart (1995) and Podolny et al. (1996). The basic idea is to exploit information derived from patent citations to characterise the research *profile* of a patenting organisation. More specifically, for each patenting organisation, the methodology computes two measures defined, respectively, as *crowding* and *importance*.

As far as the former is concerned, patent *co-citations* are used to identify the degree of similarity in the research profile between pairs of organisations. Taking a pair of patenting organisations in a broad technological field, one may argue that their research profile is very similar (i.e. their research directions are very similar) to the extent that their current patents build upon (i.e. cite) the same prior patents. For a given organisation, its *crowding* measure is simply the sum of the pairwise similarity with all other organisations. A higher value of crowding indicates that the research direction of that organisation overlaps with the research trajectories of many other organisations. Thus, the crowding measure is meant to capture the extent to which the 'technological niche' occupied by an organisation overlaps with the niche of many other organisations, i.e. it makes research areas where its research efforts overlap and are redundant with those of other organisations. An organisation with a high value of crowding is following a strategy of exploitation of a well-established technological trajectory. On the contrary, a company with a lower value of crowding is more likely to follow a strategy of exploration of new fields of research.

As far as the measure of *importance* is concerned, it builds upon the idea that the number of citations received by a patent (forward citations) are an indicator of the technological importance of the invention. Therefore, the extent to which the patents produced by an organisation receive many citations from the patents of other organisation can be interpreted as a signal that those patents represent a source of valuable new ideas and open up new opportunities for a broad set of other organisations[ix].

Computing the two indicators for each patenting organisation within a broad field of technology and plotting them in a two-dimensional space yields a visual representation of the position occupied by each organisation in terms of crowding and importance of its research activity. More specifically, the average values across all organisations of the crowding and importance measures partition the space in four areas, which identify different types of organisations:

- *Leading technology exploiters*. These are organisations with a higher than average crowding and a higher than average importance. They are key sources of knowledge spillovers for many other organizations in the industry, but the focus of their research activity is geared towards the exploitation of opportunities in relatively mature and therefore highly crowded fields.
- *Innovative technology explorers*. These are organisations with a lower than average crowding and a higher than average importance. These are highly cited organisations that do research in fields not yet explored by other organisations. These organizations can be thought of as brokers of new technologies, to convey the idea that they are the sources of knowledge in relatively new and unexplored fields.
- *Technological followers*. These are organisations with a higher than average crowding and a lower than average importance. The research made by these organisations does not provide significant benefits (i.e. citations) to other organizations and they engage into relatively mature and crowded technological areas.

- *Technological isolates and pioneers*. These are organisations with a lower than average crowding and a lower than average importance. Their patents do not receive citations from other organizations and they are engaged in exploring relatively untapped technological areas. It is possible that few of them shift over time to become brokers of new technologies. However, it is also likely that most of them are good candidates for exiting the industry. One may expect that high rates of entry and exit from the industry (and/or from the technology) take place exactly in this group of firms.

2.3.2 Strengths and weakness of methodology

The methodology adopted is to some extent complementary to the one described above to identify leading national research organisations. While the identification of leading research organizations was based on the use of *scientific publications*, the notion of leaders in ICT fields adopted in this section is based on the use of *patent data*. In other words, the type of leaders examined here relate to the realm of applied research and technological development, rather than to that of basic science. Moreover, the notion of leadership used here derives from citation data, rather than from the sheer volume of output. Thus, an organization can be considered as a leader as long as its patents receive a large number of citations, even if it does not produce a large number of patents.

The methodology adopted has also some obvious limitations. In the first place, it relies upon the use of patents and patent citations data. A large and growing body of recent research has attempted to validate the use of patent citations as an indicator of knowledge flows and quality of technological output. Nonetheless, this remains a noisy indicator. Second, in the taxonomy illustrated above some categories may contain a rather heterogeneous set of organisations. In particular, the category of technological isolates is highly populated. Yet, the types of companies included in that category are likely to be quite differentiated. On the one hand, there are probably many organisations whose innovation output (i.e. patents) is not cited because the research trajectory is a dead-end. On the other hand, a few of those isolates may be working on potentially promising ideas and new research trajectories, which are not cited by other, larger organisations because they have not yet recognized the opportunities existing in those areas.

2.4 Findings and policy insights

The main results of our analysis are reported in the following figure. The upper right panel reports the *leading technology exploiters*, i.e. organizations whose patents have a higher than average importance and operating in relatively crowded technological niches. They are recognized as leading organizations in the field by other organizations and their innovative activities have high overlaps with those of other actors in the ICT industry. While only 6% of all European patenting organizations are classified in this category, the share of leaders among participants in the FPs rises to 20%. This implies that FPs tend to attract a disproportionate share of leading technology exploiters.

Organizations located in the upper-left quadrant are *innovative technology explorers*. The fraction of all European patenting organizations falling in this category is 3.4%, as opposed to 6.1% of European organizations that participate in the FPs. Once again, this suggests that the FPs tend to involve a larger than expected share of organizations engaged in the exploration of new technologies.

Looking at *technological followers* (i.e. bottom right quadrant of the matrix), 36% of all participants in the FPs are located here compared to 28% if one takes the whole population of European patenting organizations. So, the FPs tend to attract a relatively larger share of organizations located in this area. Finally, *technological* isolates and pioneers (i.e. lower left panel) comprise the vast majority of European patenting organizations: almost 63% of them are positioned here. Yet, only 38% of participants into FPs are located in this quadrant, thus suggesting that this type of organizations is less likely to be involved in the FPs.

Figure 1: A taxonomy of European patenting organisations

Innovative technology explorers Nr of European organizations: 336 (3,43%) Nr of FP participants: 56 (6,11%)	*Leading technology exploiters* Nr of European organizations: 588 (6,01%) Nr of FP participants: 181 (19,76%)
Technological isolates Nr of European organizations: 6127 (62,61%) Nr of FP participants: 350 (38,21%)	*Technological followers* Nr of European organizations: 2735 (27,95%) Nr of FP participants: 329 (35,92%)

Average Importance

Average *Crowding*

Note: the percentage values in each quadrant refer, respectively (i) to the fraction of European organizations falling in that quadrant over the total number of European organizations patenting in the ICT fields and (ii) to the fraction of patenting participants in the FP falling in that quadrant over the total number of patenting participants in the FPs.

Analytical insight*:* The past FPs have been effective in attracting leading technology *exploiters* and innovative technology *explorers*. Both types of organizations are important sources of knowledge spillovers for many other organizations in industry. However, while the former focus their research activities towards the exploitation of opportunities in relatively mature fields, the latter are organisations that do research in relatively new and unexplored fields. Both types of actors tend to be found among relatively large and quite established organisations. At the same time, the selection process into the FPs filters out technology pioneers and isolates. This group includes heterogeneous organisations. Whereas the majority of them are likely to work on less original and fertile projects, few of them are pioneers, namely they are engaged on exploratory ideas, not yet seized by other and larger companies. Designing appropriate instruments to identify, select and include those organisations seems to be an important challenge for future designs of RTD collaborative activities.

Conclusion*: The identification and inclusion of the most explorative innovators should be enhanced.*

3 ICT RTD Network analysis

The core part of the service study has been an analysis of the collaborative networks that have emerged from the FP6 and FP7 in the ICT RTD thematic area. Two major analytical tasks have been carried out:

- An investigation of the profile of FP participants and of the process of formation and deletion (i.e. not repetition) of collaborative ties;
- An analysis of the positioning of European organisations in the various alliance and knowledge networks.

In what follows, we describe in detail the objectives, methodology, findings and policy insights emerging from this analysis.

3.1 Profile of participants

The major objective of this analytical task has been to outline in a descriptive way the main characteristics of the collaboration network emerging from the FPs and of the evolution of such a network from the FP6 to the FP7. A particular attention has been devoted to examining the extent to which organisations participate repeatedly in FPs and also the extent to which they tend to engage in collaboration with same partners over time.

3.1.1 Methodology

This first analytical component adopts a descriptive approach, without use of social network analysis techniques and methods. The levels of analysis are either the single "node" of the network, i.e. the single organisation participating in the FP, or the "dyad" , i.e. a pair of organisations collaborating on the same projects. As far as the *nodes* of the network are concerned, our analysis has been conducted at the level of "main organisations". For example, all the different departments and research institutes of ETH Zurich have been considered as a single *node* in the network, and not as distinct and separate nodes.

3.1.2 Strengths and weaknesses of methodology

To the best of our knowledge, this is one of the first study addressing the problem of the process of tie formation in the FP network. This is a major strength of our approach. At the same time, there are two main weaknesses that have to be taken into account. First, our analysis is conducted at the level of main organisations (see section above). Our findings might change if the analysis were carried out at the level of sub-entities within major organisations. As already discussed, however, there is a both a data problem (i.e. CORDIS database does not allow a correct identification of these sub-entities or it is too time consuming to identify them) and it is not clear from a conceptual perspective what is the "correct" organisational level at which network analysis should be conducted. Secondly, our analysis is mostly descriptive and thus it does not capture the factors causing the patterns that we observe.

3.1.3 Findings and policy insights

The vast majority of participants in the FPs are *occasional*, i.e. they participate in only one project. Only 35% and 36% of all FP6 and FP7 participants have participated in more than one project. When one looks at the types of participants, a few striking differences emerge (see table below). First, the share of companies in terms of *participations* is significantly lower than the share of companies in terms of distinct *organisations*. The opposite pattern holds for universities and for research organisations. This indicates a remarkably higher participation intensity by research organisations than by industry actors. In other words, firms tend to participate less frequently and to fewer projects than actors from research thus resulting in greater participation intensity by scientific actors. On average, an industrial actor participated in 2.03 FP6 and 1.97 FP7 projects. The corresponding values for universities are 6.95 and 5.72, whereas the average public research organisations took part in 5.37 FP6 and 4.94 FP7 projects. Second, the participation rate of industry actors, both in terms of distinct organisations and in terms of participations, is reducing going from the FP6 to FP7, while the share of universities is increasing. Although these changes are not dramatic, they confirm a trend already noted with respect to the FP5 and the FP6

Table 2: Participation rates in FPs, breakdown by organisation type, FP6-FP7

	FP6				FP7			
	Organisations		Participations		Organisations		Participations	
	Nr	%	Nr	%	Nr	%	Nr	%
Companies	2845	56.89	5769	38.14	2124	55.11	4193	36.74
Associations	72	1.44	259	1.71	168	4.36	357	3.13
Others	868	17.36	1216	8.04	399	10.35	589	5.16
Private research organizations	77	1.54	480	3.17	102	2.65	430	3.77
Public research organizations	325	6.5	1744	11.53	291	7.55	1437	12.59
Universities	814	16.28	5659	37.41	770	19.98	4406	38.61
Total	5001	100.00	15127	100.00	3854	100.00	11412	100.00

Note: the first two columns of the table reports the (unweighted) distribution of organisations participating in FP6 and FP7, while the third and fourth columns report the same distribution but weighting each participant by the total number of project participations.

Besides participating in multiple projects within the *same* FP, organisations may also participate in different projects *across* FPs. To investigate this, we have focused on the FP7 and we have split organisations participating in FP7 projects into *new* and *persistent* organisations. The former are organisations participating for the first time in the FP7 (i.e. they have not participated in FP6), whereas the latter are organisations that participate in the FP7 *and* have already participated in the FP6. Moreover, we also identified among the organisations that participated in the FP6 those that did not participate again in the FP7 labelling them as *occasional*.

Results show that, compared to their share among participants in FP7, industrial actors are over-represented among *new* participants and under-represented among *persistent* participants. More than 60% of all *new* participants are firms, whereas (about 43%) of all *returning* organisations are either universities or research organisations (see top panel of the table below).

Overall, the available evidence seems to show the existence of two polar patterns of participation into the FPs. The first is typical of industrial actors, especially small and medium sized companies, and it is characterised by the occasional participation into just one or very few projects. The second is typical of (large) universities and research organisations (and also very large companies) and it is characterised by the persistent participation into a relatively large number of projects.

Table 3: Persistent, new and occasional participants

	Persistent		New		Occasional	
	Nr	%	Nr	%	Nr	%
Companies	724	46.14	1400	61.27	2121	61.80
Associations	25	1.59	143	6.26	47	1.37
Others	141	8.99	258	11.29	727	21.18
Private research organizations	47	3.00	55	2.41	30	0.87
Public research organizations	126	8.03	165	7.22	199	5.80
Universities	506	32.25	264	11.55	308	8.97
Total	1569	100.00	2285	100.00	3432	100.00

Note: Persistent are organisations that participated in the FP6 and participated again in the FP7. New are organisations that participated for the first time in the FP7 (i.e. they did not participate into projects in the FP6). Occasional are organisations that participated in the FP6 but did not participate again in the FP7.

A very important issue in evaluating the FPs concerns the evolution of the FP network. In this respect, we investigated the process of *tie* formation, dissolution and repetition. In this context, there is a *tie* when two organisations are linked by the fact of having co-participated in at least one project. How many of the ties formed in the FP6 are then *repeated* in the FP7? How many of them are not repeated, namely they are *dissolved*? Moreover, how many of the ties formed in the FP7 are among organisations that never collaborated before?

In order to address these issues, we proceeded in two ways:

- First, we looked at the ties formed in the FP6 and we computed how many of them have been repeated in the following FP and how many have been dissolved, i.e. have not been repeated.
- Second, we looked at the ties formed in the FP7 and we computed how many of them involved new organisations (i.e. organisations that did not participate in the FP6) and how many involved persistent participants.

Before illustrating the findings, it is important to remark that in a project with n participants there are $n(n-1)/2$ ties. This implies that the total number of ties observed depends on the average size of projects. For example a project with 12 participants generate (12x11)/2=66 ties, whereas a project with 9 participants generate (9x8)/2=36 ties. In this respect, it must be noted that the average number of participants decreased from 12.3 in the FP6 to 9.4 in the FP7.

Table 4: Repetition, formation and dissolution of network ties

	FP6 Nr	FP6 %
Total number of ties	110819	100.00
of which		
both organisations did not participate again in the FP7	16632	15.01
at least one organisation did not participate again in the FP7	46177	41.67
both organisations participated again in the FP7	48010	43.32
of which ←		
The two organisations co-operated again in the FP7	12077	25.16
The two organisations did not co-operate again in the FP7	35933	74.84
	FP7 Nr	**FP7 %**
Total number of ties	55588	100.00
of which		
none of the two organisations participated in the FP6	6451	11.60
at least one organisation was not participating in the FP6	21649	38.95
both organisations did participate in the FP6	27488	49.45
of which ←		
The two organisations already co-operated in the FP6	12077	43.94
The two organisations were not co-operating in the FP6	15411	56.06

The evidence shows that the total number of ties in the FP7 are about half of those established in the FP6. This is due to two reasons. On the one hand, FP7 data are partial, i.e. they only cover project calls up to August 2010. On the other hand, the average size of projects in the FP7 has remarkably decreased compared to the FP6.

Looking at the top panel of the table above, we observe that of all ties formed in the FP6 43% were among organisations that later on participated again in the FP7. Thus, persistent participants account for a relatively low fraction of all participants (around 31%), but for a relatively large share of all ties. Looking at this result from another perspective, persistent participants tend to participate in many projects and therefore establish a large number of ties. An interesting question is how many of the ties formed in the FP6 are then repeated (i.e. maintained) in the FP7. Of the 48010 ties formed in the FP6 among persistent participants, only 25% were repeated in the FP7. In other words, the vast majority of ties formed in the FP6 were not repeated in the FP7. One way to read these numbers is as follows. If we take two organisations that collaborated in the FP6, the probability that they collaborated again in the FP7, *conditional on the fact that both of them participated in the FP7*, is quite low, around 0.25. This suggests that research teams among persistent organisations tend to change to a rather large extent. However, it is also important to stress that part of the explanation for this result is due to the lower average number of participants per project in the FP7 compared to the FP6.

If we turn the attention to the FP7 (bottom panel of the table above), we observe that out of all ties established in the FP7, 49% involve two organisations that were participating in the FP6. Of these ties, 44% are "repeated" ties, namely they involve two organisations that were already collaborating in the FP6, whereas 56 are "newly established" ties, namely they involve two organisations that were already participating in the FP6 but were not collaborating with each other.

In our view, these figures suggest a picture of the evolution of the FP network, in which a relatively small core of organisations persistently participate in the FP projects, but in which the tendency to repeat the same set of ties among them is relatively low. It is worth repeating again, however, that the extent of persistency in ties depends to a large extent on the average size of projects, which has been falling from the FP6 to the FP7[x].

Analytical insight*:* The available evidence suggests a picture of the evolution of the FP network, in which a core of established organisations (mostly large universities and public research organisations) persistently participate across the different FPs, accounting for the vast majority of the ties established in each FP. On the other hand, lower persistency in the participation rates characterise the industry actors, especially small and medium sized companies. Moreover, a relatively large fraction of all ties established in a FP involves pairs of organisations that have been already collaborating in the previous FP. This suggests a rather high degree of *inertia* in the patterns of collaboration. In our view, the design of policy instruments should address the causes of the low participation rates of small industry players and should ensure a greater rate of recombination of collaborative partners.

***Conclusion**: The design of programmes should address the low persistency in participation and the inertial tendencies in collaboration.*

3.2 Network Hubs

The major objective of this analytical task has been to define and identify Hub organizations and to determine their effectiveness in creating and diffusing knowledge. Informally a Hub may be defined as a node (organization) with a very large number of connections or one that is highly influential by playing the role of network connector, connecting nodes that would otherwise remain unconnected. Network Hubs are critical in determining the overall connectivity of the network as well as its topological properties. Network structure changes dramatically once one removes from the network the most connected nodes thereby decreasing the ability of the remaining nodes to interact with each other.

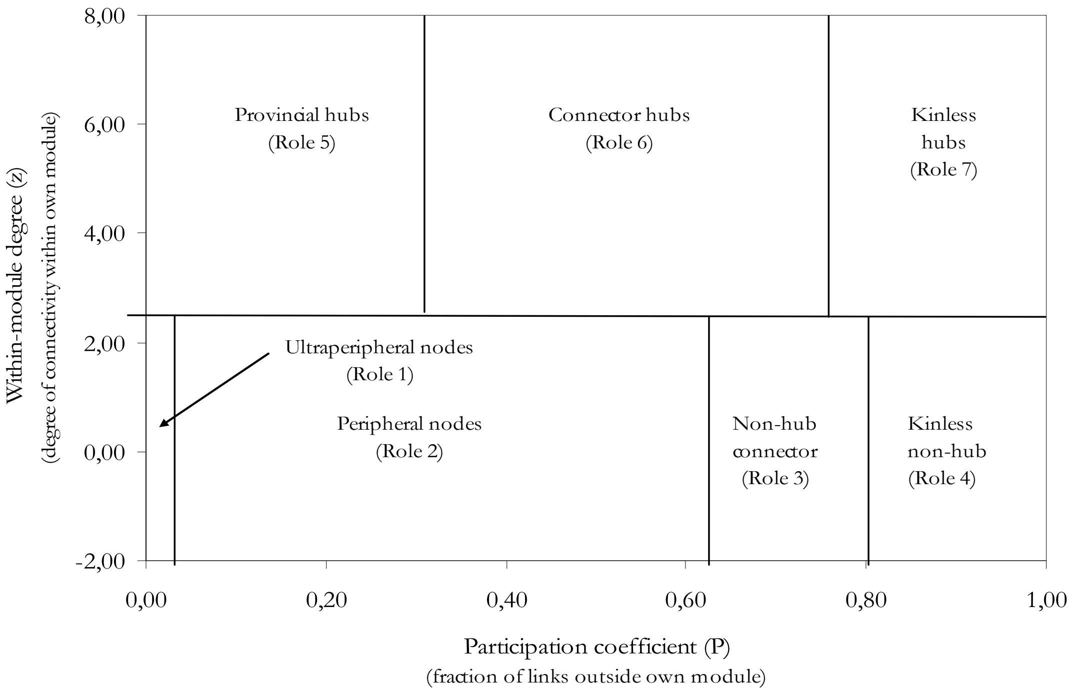
3.2.1 Methodology

We use all different networks developed in this study as summarized in earlier sections: the ICT RTD network, the global RTD network, the patent citation network, the patent co-citation network, and the mobility network. Because the global RTD network has been found disjoint, we essentially drop it from the analysis.

To identify Hub organizations in these networks, we adopt the algorithm proposed by Guimera and Amaral (2005) which uses the concept of modules (communities of organizations) and classifies nodes (organizations) according to their degree of connectivity within and between modules (

Figure *2*).

Figure 2: Partition of Nodes (Network Participants)



Source: Adapted from Guimera and Amaral (2005)

Hubs are nodes with high connectivity within their primary module. The rest are classified as non-hubs. In addition nodes are classified in terms of their connectivity across modules. Figure 2 indicates seven different types of nodes. The nodes at the top right part of the graph are very active in connecting within their module as well as across modules: kinless hubs (Role 7) and connector hubs (Role 6). They are the most connected organizations. The ones at the bottom left of the graph exhibit low connectivity within their own module and across modules: ultraperipheral nodes (Role 1) and peripheral nodes (Role 2). They are the least connected organizations and, of course, non-hubs. The nodes at the top left of the graph are hubs, i.e., well connected within their module, but much less, if at all, connected across modules: provincial hubs (Role 5). Finally, the nodes at the bottom right of the graph are non-hubs (not much connected within their respective modules), but highly connected across modules: non-hub connectors (Role 3) and kinless non-hub (Role 4).

3.2.2 Strengths and weaknesses of methodology

The most obvious approach to identify network hubs is to rank nodes (organizations) in terms of the number of their partners. Hubs would then be the nodes with significantly higher connectivity than the average. Another approach is to rank organizations in terms of their particular location in the network that facilitates connections between otherwise disconnected parts of the network. Or one could merge the two and single out the nodes with the highest combined values. While such an approach has been utilized frequently in the past, it suffers from lack of specificity to represent the great variety or roles of network participants. The methodology followed here is much more fine grained and combines connectivity within the primary module (community) of a node (organization) with connectivity across modules. It thus first identifies coherent "communities" or "neighbourhoods" and then looks at the connectivity role of individual organizations within and across such communities.

The major weakness of the methodology as far as this study goes is that we have not tried to identify what makes such communities. Is the community defined in terms of technological proximity? Is it defined in terms of broad categorization of sectoral space? (Say, microelectronics, or software) Are these communities defined by behavioural similarities across their members? Future studies should try to get at that. A second weakness, also mentioned in earlier sections, is that our analysis is conducted at the level of main organisations. Our findings might change if the analysis were carried out at the level of sub-entities within major organisations.

3.2.3 Findings and policy insights

Tables 5 and 6 below show the node distribution by Role in the five networks under consideration and the node distribution in these networks by organizational type.

Table 5: Participating Organizations (Nodes) Distribution by Role in the Network[3]

	Non-hub nodes				Hub nodes			Total
	Role 1	Role 2	Role 3	Role 4	Role 5	Role 6	Role 7	
	Ultraperipheral	Peripheral	Non-hub Connectors	Kinless Non-hubs	Provincial Hubs	Connector Hubs	Kinless Hubs	
Global RTD Network	188	18	1	0	0	0	0	207
ICT RTD Network (FP)	142	3,049	1,997	166	5	72	85	5,516
Patent Citation Network	538	877	167	0	4	56	0	1,642
Patent Co-citation Network	333	835	0	0	0	43	0	1,211
Mobility Network	426	420	187	6	3	10	1	1,053

[3] We also calculated this distribution for the FP6 IST RTD Network and the FP7 ICT RTD Network separately and found similar distribution with the aggregate network presented here.

Table 6: Network Participant (Node) Distribution by Organizational Type

	Global RTD Network		ICT RTD Network		Patent Citation Network		Patent Co-citation Network		Mobility Network	
	Organizations (%)	Hubs (%)	Organizations (%)	Hubs (%)	Organizations (%)	Hubs (%)	Organizations (%)	Hubs (%)	Organizations (%)	Hubs (%)
University	2 (0.97)	0 (0)	876 (15.88)	85 (52.47)	440 (26.80)	0 (0)	371 (30.66)	0 (0)	407 (38.65)	2 (14.29)
Industry	197 (95.17)	0 (0)	3,351 (60.76)	48 (29.63)	817 (49.76)	52 (86.67)	704 (58.18)	38 (88.37)	508 (48.24)	6 (42.86)
Public research institute	5 (2.42)	0 (0)	724 (13.13)	7 (4.32)	22 (1.34)	2 (3.33)	16 (1.32)	1 (2.33)	20 (1.90)	0 (0)
Others	3 (1.45)	0 (0)	565 (10.24)	22 (13.58)	363 (22.11)	6 (10.00)	120 (9.91)	0 (0)	118 (11.21)	6 (42.86)
Total	207 (100)	0 (100)	5,516 (100)	162 (100)	1,642 (100)	60 (100)	1,211 (100)	43 (100)	1,053 (100)	14 (100)

Several important observations are in order:

- In all examined networks, the majority of organizations can be characterized as ultra-peripheral or peripheral (least connected).
- However, and in contrast to the rest, the ICT RTD network:
- Distributes organizations (nodes) across all categories;
- Leaves a smaller fraction of organizations in the ultra-peripheral category;
- Has 3% of its nodes as hubs in their modules;
- Indicates a good share of the network participants that are 'highly nomadic' – i.e., maintaining a high fraction of their links across modules (Roles 3, 4, 6, 7) – including both hubs (Roles 6, 7) and non-hubs (Roles 3, 4). These organizations can be said to frequently venture beyond their narrow worlds (communities) to meet different types of partners, arguably with a different set of capabilities;
- Is the only network with several nodes in the highly 'nomadic' category of Role 7 hubs.
- The ICT RTD network appears to suggest a 3-tier structure in FP consisting of the core (highly connected hubs), non-hub connectors, and the periphery.
- While the three networks constructed on patent-related information also have hubs – patent citation network, patent co-citation network, and mobility network – they have no or few 'highly nomadic' nodes, in contrast to the ICT RTD Network. This suggests that hub nodes in patent-based networks tend to be mostly connected to other nodes within the same neighbourhood (module). They typically do not function as connectors between modules.
- The ICT RTD Network and the three patent-based networks possess contrasting node distribution. The university share in hub nodes is disproportionally large in the ICT RTD Network (52%). No less than 70% of hubs in this network are non-industry. In contrast, more than 85% of the hub organizations in the Patent Citation Network and the Patent Co-Citation Network originate in industry.
- The overwhelming majority of hub nodes in the ICT RTD Network are European organizations (85%). The share of European organizations in hubs drops significantly in both the Patent Citation Network (53%) and the Patent Co-citation Network (53%). The US shares increase significantly in these two patent networks. Japanese shares increase somewhat.

Analytical insight*:* The emergent networks we examine in this study are not different from typical scale-free networks in prior literature: the large majority of participants live in the periphery whereas a small proportion of them are highly connected. However, the ICT RTD Network appears significantly different than the rest as it has a much more balanced distribution of nodes across categories. In fact, the ICT RTD Network seems to indicate a 3-tier structure in the Framework Programme consisting of (i) a hard core (highly connected hubs), (ii) a large set of non-hub connectors (nomads, connecting across modules), and (iii) the periphery. Whereas earlier studies have stressed the two extremes, this is the first time that we are seeing an important middle.

***Conclusion**: The ICT RTD Network already has a balanced structure in terms of distributing participants across hub/non-hub and nomadic/non-nomadic categories. This distributive structure is, on the whole, good news for inclusion.*

Analytical insight*:* A good majority of ICT RTD Network hubs are public research and teaching organizations. This corroborates with a long series of earlier findings in evaluating the Framework Programmes over the years. Respondents to questionnaires have time and again stressed benefits from participation as being primarily intangible and indirect (networking, information gathering, capability building) rather than direct benefits in terms of products and process innovations. This is not to say that the Programme is not useful or well focused. In fact the Programme for a long time since its inception was considered an instrument to promote pre-competitive research. It is in more recent years that emphasis in the political realm has gradually shifted towards application / innovation. If the expectations for the Programme are changing, then it may not yet be adequately reflected in the composition of research consortia.

***Conclusion**: The ICT RTD Network is deeply influenced by public research and teaching organizations, which is in line with the pre competitive nature of the FP's. If the FP policy trend keeps shifting towards exploitation and innovation, this shift needs to be translated into instruments enabling more innovation-oriented organisations to take a hub role.*

Analytical insight*:* The share of hubs claimed by European organizations drops significantly when one moves from the ICT RTD Network to the Patent Citation and Patent Co-citation Networks. The caveat here is that ICT RTD Network hubs are heavily populated by higher education and public research organizations whereas the patent networks' hubs are dominated by private sector companies. A drop-off would thus be expected.

***Conclusion**: While ICT RTD projects help foster strong networks among European organizations, policies and instruments need to be developed to better translate the benefits into core roles in patent-centric networks.*

3.3 Effectiveness in Producing and Disseminating Knowledge

The service study required assessing the effectiveness of Hubs and other participating organizations in the ICT RTD Network in producing and diffusing knowledge.

3.3.1 Methodology

We assess the extent to which organizations effectively work as knowledge depositories and/or recognized sources of information and ideas for others. Effectiveness, in this sense, reflects the contribution of an organization in enriching the knowledge network with new knowledge and in facilitating the dissemination of knowledge among network members. To this purpose, we exploit the available patent data to derive various indicators of knowledge creation and diffusion. We use three indicators to capture the effectiveness of organizations in producing knowledge: number of patents in a field, number of citations received, and number of highly cited patents. We use two additional indicators to capture the effectiveness in disseminating knowledge: degree centrality, and betweeness centrality.

3.3.2 Strengths and weakness of methodology

We use numeric indicators with unambiguous results. On the other hand, patent citation patterns are not without problems when used as indicators of knowledge dissemination. Moreover, the extent to which patents adequately capture knowledge creation as such is also debatable as knowledge comes in various forms and degrees of embededness. In particular here given the fact that, as shown above, many of the hubs are higher education organizations and other public research institutes for which patenting may not be their strategic focus. Similar indicators using data on scientific publications would nicely complement the current results.

3.3.3 Findings and policy insights

Results show that the 'highly nomadic' kinless hubs (Role 7) – the most connected organizations in our study – perform, on average, at a level of magnitude above all others. They are much more effective in terms of both production and dissemination of knowledge. At some distance they are followed by the next category of most connected organizatons – connector hubs (Role 6). Again at some distance, kinless non-hubs (Role 4) come third. They correspond to organizations that are not hubs in their modules but maintain a very large proportion of their linkages outside the module. Connector provincial hubs (Role 5) come dead last.

Analytical insight: There is a strong positive relationship between knowledge creation and dissemination effectiveness and the rate of connectivity. In fact, it is connectivity that matters, not necessarily intra- or inter-module connectivity.

***Conclusion**: The most connected organizations in the ICT RTD Network are also the most effective in creating and disseminating knowledge.*

3.4 Role of Different Funding Instruments in Bridging Organizations

This section assesses the relative importance of the different funding instruments – Integrated Projects (IPs), Specific Targeted Research Projects (STRePs), and Networks of Excellence (NoEs) – in determining the structural features of the various networks.

3.4.1 Methodology

To accomplish this, we conduct sensitivity analysis which consists of removing from the focal network all projects (and related organisations) funded by the targeted instrument and observing the impact of the removal on the structural properties of the network. The implicit argument is that the more sensitive (vulnerable) the structure of the network – in terms of measures like number of linkages, density, average path length, number of hubs, and so on – is to the removal of instrument-specific projects, the more important the instrument under examination is to the network. We harmonized the data between the two Framework Pogrammes by breaking down the FP7 collaborative research projects (CP) into the IP and STReP categories of FP6.

3.4.2 Strengths and weakness of methodology

Simple straightforward sensitivity analysis is involved here. The only question may relate to the definition of the dividing line between IP and STReP. We used the average project sizes in FP6 to do so.

3.4.3 Findings and policy insights

Looking at the ICT RTD Network, the removal of NoEs results in the loss of 4% of the participating organizations (nodes) and 1/5 of the connections, with a total loss of about 1/10 of total participations. The ICT RTD Network remains robust. The removal of IPs, on the other hand, results in the loss of almost 1/3 (30%) of the organizations and almost half (47%) of the connections. While this effect is in itself quite significant – loss of about 2/5 of the overall program participations – network structure does not change dramatically. The network appears fairly robust in the removal of such a big chunk of it! Still, the fact that thirty percent of organizations in the network only participate in IP-funded projects indicates that the IP instrument captures many organizations that otherwise would not participate into the Framework Programme. Finally, the removal of STRePs results in the loss of 2/5 (41%) of participating organizations, almost one quarter (23%) of the connections, and half of all network participations. These numbers suggest that STReP projects account for many of the peripheral participants of the network. This is further corroborated by the fact that the removal of STRePs results in a very significant increase in network density whereas it leaves the other vital network characteristics more or less unchanged.

Analytical insight*:* The ICT RTD Programmes harness network linkages among a large number of participants. The resulting network is robust in the sense that its vital signs remain healthy and fairly unchanged with the removal of single most important funding instruments. Different instruments, however, play different roles. Whereas IPs look like the backbone in terms of the sheer number of participations and network location of organizations they account for, STRePs are very important in terms of bringing new participants (more peripheral) into the network. Among the three examined instruments, NOEs is the least prominent in terms of structural effects onto the network if removed.

Conclusion*: The ICT RTD network will survive shocks as big as the removal of single most important funding instruments like IPs or STRePs. Nevertheless, this should be limited or avoided as the loss of a big instrument like that will result in the loss of large numbers of participating organizations. In the case of STRePs more than any other, new, more peripheral participants will be removed.*

Turning to the Patent Citation Network, it emerged stable and cohesive, remaining robust against the removal of individual funding instruments. IP and STReP participants account for significant shares of the network – close to one fifth of the participating organizations and a quarter or more of the connections in each case. However, their individual removal does not result in any sort of network collapse. The removal of NoEs resulted in no discernible effect on the network. These funding instruments enrich the network but do not necessarily provide the foundations of either the network or the underlying knowledge diffusion (through patent citations). Similar results were obtained for the Patent Co-citation Network. The elimination of IPs or STRePs would result in a significantly thinner Mobility Network (roughly by a quarter in each case).

We have also performed the same sensitivity analysis for all four networks looking at the effects of selective funding instrument removal on the distribution of network participating organizations (nodes) across the different categories (Roles) of Figure 2. Results are summarized in Table 7 below and are quite interesting:

- ICT RTD Network (FP): Removal of NoEs does not change much barring a redistribution of roles in the connector hubs (Role 6) (a quarter drop) and kinless non-hub (Role 4) (increase by three quarters). Removal of IPs results in a steep drop of connector hubs (Role 6) (decrease by two thirds), elimination of the provincial hubs (Role 5) and serious decreases of non-hub connectors (Role 3) and peripheral nodes (Role 2). Removal of STRePs results in very significant decreases across all categories, both hub and non-hub.
- Patent Citation Network: Removal of NoEs has almost no effect. Removal of IPs has a strong effect on provincial hubs (Role 5) and a fairly limited effect on other categories. Removal of STRePs has some effect on all categories, especially non-hub.
- Patent Co-citation Network: Removal of NoEs is not felt. Removal of IPs has significant effects on ultraperipheral nodes (Role 1), peripheral nodes (Role 2),

and connector hubs (Role 6). Removal of STRePs also has significant effects on the same categories plus very importantly on non-hub connectors (Role 3).

- Mobility Network: Removal of NoEs has fairly small effects. Removal of IPs and STRePs, on the other hand, has extensive effects across all categories in terms of thinning them out. The effect is relatively the largest in the case of STRePs.

Table 7:Distribution of Participating Organizations (Nodes) by Hub Role Across Five Networks (sensitivity analysis)

Network type	Category	Number of nodes							Total number of nodes
		Non-hub nodes				Hub nodes			
		Role 1	Role 2	Role 3	Role 4	Role 5	Role 6	Role 7	
		Ultraperipheral nodes	Peripheral nodes	Non-hub connector	Kinless non-hub	Provincial hubs	Connector hubs	Kinless hubs	
Global RTD Network	All alliances	188	18	1	0	0	0	0	207
ICT RTD Network	All FP projects	142	3,049	1,997	166	5	72	85	5,516
	No FP-IP projects	178	2,016	1,356	192	0	26	84	3,852
	No FP-NoE projects	133	2,947	1,805	295	4	53	83	5,320
	No FP-STReP projects	36	1,906	1,175	73	1	33	45	3,269
Patent Citation Network	All FP projects	538	877	167	0	4	56	0	1,642
	No FP-IP projects	475	721	119	0	1	46	0	1,362
	No FP-NoE projects	532	873	155	0	4	52	0	1,616
	No FP-STReP projects	455	706	106	0	2	47	0	1,316
Patent Co-citation Network	All FP projects	333	835	0	0	0	43	0	1,211
	No FP-IP projects	278	586	0	0	0	33	0	897
	No FP-NoE projects	331	813	0	0	0	43	0	1,187
	No FP-STReP projects	194	568	76	0	0	32	0	870
Mobility Network	All FP projects	426	420	187	6	3	10	1	1,053
	No FP-IP projects	324	332	131	1	0	21	0	809
	No FP-NoE projects	386	429	191	6	0	13	3	1,028
	No FP-STReP projects	287	268	190	31	1	7	9	793

Analytical insight*:* Consistent with the prior sensitivity analyses in this Section, NoEs appear to be the least influential funding instrument across all networks. The story is different for IPs and STRePs. Removal or either IPs or STRePs results into deep cuts in terms of participating organizations. If anything, the influence of IPs is extensive but somewhat more concentrated in terms of node categories compared to the influence of STRePs which comes across all categories. Take, for instance, the case of the ICT RTD Network (FP). Elimination of IPs affects extensively two of the three hub categories and also seriously several non-hub categories of participants. It is, however, the elimination of STRePs which cuts deep across all participant categories. Similarly with the patent-based networks.

Conclusion*: IPs and STRePs provide the backbone of the examined networks and must continue receiving significant attention by program managers and policy makers.*

How important are organizations in the various categories (Roles) of Figure 2 in determining the core characteristics of the ICT RTD Network? The question has policy interest because hub nodes (participating organizations) are typically viewed as the backbone of the network, keeping the pieces together. To answer this question we performed sensitivity analysis of the network by gradually removing groups of participating organizations in the different node categories of Figure 2. Results are reported in Table 8.

The first thing to notice is the huge effect of a small number of organizations in a single category: 86 kinless hubs (Role 7) (out of a total 5,516 organizations) account for 38% of all linkages in the network. When they are removed the number of network components rises from 1 to 7 and the core characteristics of the network are deeply affected. The assortativity coefficient – measuring the tendency of nodes to link to other nodes with similar degree – turns from negative to positive suggesting that kinless hubs are distinct from other organizations. Network betweenness becomes much smaller (one-third), suggesting that network linkages are extensively concentrated on kinless hubs. In other words, kinless hubs are of critical importance for the ICT RTD Network.

The next group of network participants, 74 connector hubs (Role 6), has the second most important influence on the ICT RTD Network. Their elimination results yet in another very serious cut of connections (edges), decrease in average degree, increase in the assortativity coefficient, and more than doubling of the network components. Interestingly, though, the characteristics within the largest component remain more or less the same.

The network remains fairly stable with the removal of the few provincial hubs (Role 5) and 173 kinless non-hubs (Role 4), save for a large jump in the number of components in the latter case.

The next major change in the ICT RTD Network comes with the removal of non-hub connectors (2,074 organizations, Role 3). The network essentially breaks down then with the jump of the number of components from 30 to 223. All other vital characteristics of the network change dramatically. There is little, if any, of network left with only participating organizations in Role 2 and Role 1 (accounting for more than half of the total network participants)

Table 8:Topological Properties of the ICT RTD Network Against Removal of Participating Organizations (Nodes) by Hub Role

	Hub roles of nodes included in network						
	Roles 1-7	Roles 1-6	Roles 1-5	Roles 1-4	Roles 1-3	Roles 1-2	Role 1
Number of nodes	5,516	5,430	5,356	5,351	5,178	3,104	133
Number of edges	119,663	73,999	58,153	57,820	49,256	15,802	377
Average degree	43.3876	27.2556	21.7151	21.6109	19.0251	10.1817	5.6692
Assortativity coefficient	-0.1330	0.0231	0.0768	0.0776	0.1193	0.6075	0.862
Network density	0.0079	0.005	0.0041	0.004	0.0037	0.0033	0.0429
Network betweenness	0.1464	0.0591	0.0508	0.0511	0.0324	0.00441	0.00831
Number of components	1	7	17	17	30	223	25
Size of the largest component	5,516	5,410	5,295	5,290	5,067	2,115	19
Network diameter*	4	7	8	8	8	15	2
Average path length*	2.5556	2.9676	3.1782	3.1812	3.3531	5.6121	1.0232
Transitivity*	0.2117	0.2616	0.2869	0.2847	0.3258	0.7478	0.9304
Average clustering coefficient*	0.8334	0.8075	0.7955	0.7957	0.7945	0.5888	0.1393

*Computed on the largest component.

(Isolated nodes are removed from the network)

Role 1: Ultraperipheral nodes

Role 2: Peripheral nodes

Role 3: Non-hub connectors

Role 4: Kinless non-hub

Role 5: Provincial hubs

Role 6 Connector hubs

Role 7: Kinless hubs

Analytical insight*:* Emphatically shown in this study, the ICT RTD Network of the past two Framework Programmes is deeply influenced by a small number of organizations. Two groups of hub organizations amounting just to 3% of all network participants hold the key in keeping the network together as we know it. A third group of non-hub organizations is large enough (38% of all participating organizations) with significant enough share of activity (linkages) to provide a base for the network. Absent these three groups of organizations, the network collapses. The most highly connected hubs have always attracted attention in policy circles. So has the periphery. We believe the story of the middle ground – non-hub, inter-module connector organizations – is new. These organizations deserve much more attention than they have received till now.

***Conclusion**: Two categories of ICT RTD Network participants deserve special attention by policy decision-makers in order to strengthen their position and ensure their role. The first includes the most connected hub organizations. The second includes a large number of relatively unglamorous non-hub organizations with high connectivity across modules.*

3.5 Impact of ICT RTD on Performance

This section of the study examined the performance of FP6 IST RTD projects as perceived by project participants and the main factors affecting performance.

3.5.1 Methodology

Innovation performance comprised four dimensions of benefits for project participants: commercial exploitation–outcomes; technical knowledge creation; internal capacity enhancement; networking. Determinants of innovation performance were aligned along four dimensions: organization-related factors; project-related factors; network-related factors; and market conditions. Each of the four dimensions of innovation performance and the four dimensions of determinants of such performance were broken up into a set of more detailed factors that the survey respondents were asked to comment on. We utilized detailed survey data for FP6 ICT project participants.

3.5.2 Strengths and weakness of methodology

Unfortunately, small numbers of identified survey respondents with fully complete questionnaires severely limited the analytical possibilities, preventing us from running formal empirical analysis. The statistical robustness of the findings could, thus, not be established.

3.5.3 Findings and policy insights

With this caveat in mind, the responses of the 71 project participants corroborate more or less with results of prior research, also including research using the same survey (but extending beyond IST).[xi] Participating organizations are reported to be research intensive. FP ICT projects are perceived as involving higher risk, focusing on emerging areas, creating significant amounts of technical knowledge, and strengthening inter-organizational networks. Several research organizations play a core role as hubs and, exactly for that reason, they influence project outcomes more towards technical knowledge creation and research capability enhancement and less on direct commercial exploitation. Companies, on the other hand look to commercial exploitation through products and processes as their main motivation to participate.

Analytical insight*:* Other dimensions of performance are at least as important as commercialisable output, including the creation of technical knowledge, research capability enhancement, and the creation / strengthening of inter-organizational networks. Appraisals of the Framework Programme must not miss these very important aspects of performance as consistently reported by project participants throughout the years.

Conclusion: *Directly commercialisable output has not been a core objective of Framework Programmes. Yet survey respondents describe significant impact on innovation, especially private companies. Policies should aim at better measuring and leveraging this impact.*

4 CONCLUSION

The main objective of this study was to develop and test methodological frameworks for assessing the effectiveness of ICT RTD networks formed in the sixth and seventh Framework Research Programmes in supporting the ERA. Towards that goal, the study has undertaken two types of analyses:

- First, we examined to what extent the European FPs have been able to attract (i) leading national research organisations, (ii) highly dynamic and innovative SMEs and (iii) technology leaders, followers, and pioneers.
- Second, we adopted the techniques and methods of social network analysis and undertook a systematic analysis of the structural properties of the various kinds of networks and of the positioning of European organisations in such networks. We paid special attention to the networks formed around collaborative ICT research supported by FP6 and FP7 and searched systematically for the contribution of different types of participating organizations and funding instruments in sustaining and enhancing these networks and, by extension, in promoting the creation and distribution of knowledge.

The analyses have resulted in a set of insights and key results that are relevant for the policy decisions and that can be summarised as follows:

1. The fact that leading national research organisations of the new Member States play a relatively minor role ***is not*** a result of the Programme design. The fact that highly dynamic SME's are underrepresented in the FP's however ***is*** a result of the Programme design;
2. Highly dynamic SME's are critical for the innovation potential of the FP networks. Where these SME's participate they generally aim for full control of a project and relatively small consortia;
3. The FP evaluation process tends to filter out smaller innovators (pioneers);
4. There is a low persistency in industry participation in general, and a high inertia in network evolution among the frequent participants;
5. The (newly identified) connector organisations keep communities (sub groups within networks) 'alive', dynamic and innovative by connecting communities and injecting 'community foreign' knowledge;

6. ICT RTD networks are mostly driven by traditional players as (large) public research organisations (hubs) which may not be appropriate to sufficiently support the shifting paradigm towards exploitation and innovation;
7. ICT networks are resilient; although removing IP's seriously reduces the size of the networks, it will not destroy them. Removal of STReP's keeps the connectedness of network as is, but it throws small players out of the network. IP and STREP are in a sense substitutes of each other from a network perspective. Removal of NoE's will only have a marginal effect on the networks.

While at the time of this study Horizon 2020 did not exist, the underlying realities are obviously identical to FP 6 and FP7. Therefore, the recommendations for future programming in the following section address central challenges of H2020, even though they were not drafted in light of the new Programme.

Horizon 2020 has three main priorities: (a) excellent science; (b) industrial leadership and innovation; (c) societal challenges. This study is clearly relevant as it deals with the most central infrastructural industrial technology (ICT) and analyses connectivity which is directly related to the production and dissemination of research results. There are three major dimensions in the study that impact future programming:

- **Participation of industry players**: The analysis fully supports the importance of extending the involvement in the networks of industrial partners, in general, and SME's, in particular. H2020 should be aiming at including highly innovative, fast growing SME's, and keeping them and other industry in the common collaborative programmes over time in order to optimise the return on investment in terms of innovation.
- **Instruments and types of organisations:** both STReP and IP type instruments are highly relevant for the effectiveness, integrity and consistency of the networks. Two types of organisations are particularly important in this respect and need special attention: Hubs (with many connections within a group or community) and Connectors (with connections across groups or communities).
- **Innovation and exploitation:** The study fully supports the importance of an integrated approach to research and innovation objectives. It is important to identify and include the most exploration-oriented organizations, policies must be developed to better translate research results into applications, and the instruments must be aligned to better leverage the results of R&D.

The following 5 key Policy-oriented recommendations can de derived from the analytical insights relevant to the priorities of the new Programme for excellent science, industrial leadership, and innovation:

Policy-oriented recommendation 1: *The identification and inclusion of the most explorative innovators can – and perhaps should – be enhanced*, since ST RTD networks already feature the leading research actors across Europe. This success does not extend to the most fast-growing and innovative SMEs of the continent.

Policy-oriented recommendation 2: *The design of FPs should address the low persistency in participation by small industry players and should push for a greater rate of recombination of research partners.* The ICT RTD network has evolved around a core of established organisations (mostly large universities and public research organisations) that persistently participate across successive FPs. On the other hand, low persistency in the participation rates characterise the industry actors, especially small and medium sized companies. Moreover, a relatively large fraction of all ties established in a FP involves pairs of organisations that have been already collaborating in the previous FP.

Policy-oriented recommendation 3: *Highly nomadic organizations, whether hubs or non-hubs, deserve special attention by policy decision-makers.* By connecting outside their immediate "neighbourhoods" they will also contribute to alleviating the tendency of stable partnering. The most connected organizations in the ICT RTD Network – highly nomadic hubs – are also the most effective in creating and disseminating knowledge. However, a second category of highly nomadic non-hub organizations – extensively connected outside their "neighbourhood" – are also emerging as very important in sustaining the Network.

Policy-oriented recommendation 4: *Maintain the distributive structure of the ICT RTD Network. On the whole, this is good for inclusion and for diversification. That being said, the current composition of the network – heavy in public research and teaching organizations – does not align well with a changing policy mandate for increased innovative application.* The ICT RTD Network already has a balanced structure in terms of distributing participants across hub/non-hub and nomadic/non-nomadic categories. This Network is deeply influenced by public research and teaching organizations. So, even though survey respondents (especially private companies) describe significant impact on innovation, directly commercialisable output has not been a core objective of Framework Programmes. This skewed participation is partly the reason why the benefits from the strong ICT RTD Network among European organizations do not fully translate into equivalently strong positioning in patent-centric networks.

Policy-oriented recommendation 5: *IPs and STRePs provide the backbone of the examined networks and must continue receiving significant attention by program managers and policy makers.* The ICT RTD network will survive shocks as big as the removal of single most important funding instruments like IPs or STRePs. Nevertheless, the loss of a big instrument like that will result in the loss of huge numbers of participating organizations. In the case of STRePs the loss will include a lot of the more peripheral network participants.

In addition to the 5 above policy oriented recommendations, and to suggesting certain principles for strategic planning and designing future ICT programmes and funding instruments, and to providing input to future FP evaluations, our results underwrite advice to Member States in terms of:

- renewed effort to promote the Programme among their most exploration-innovative SME's
- redoubled effort to place industry at the core hub positions in the ICT-RTD network
- assistance in translating research results into inventions and innovations
- increased attention to the invisible middle of participating organizations many of which, even though non-hubs in their immediate "neighbourhood", appear to play important role in linking across neighbourhoods.

It is the empirical definition of such neighbourhoods where we believe a useful next step in network analysis can come.

An appeal for higher quality data

The functionality and accuracy of results of any empirical investigation critically depends on the quality of the information used. As argued more extensively in the technical report, a high-quality network-based impact analysis and monitoring of FP initiatives would require equally high-quality data. Unfortunately, the way in which data on participation in the FPs is collected does not take into account the needs of downstream users of that information. Ideally, the collection of data on FP participations should provide:

1) A standardisation of the names of participants, together with a unique and univocal ID code;
2) The identification of the sub-units within larger organizations (such as CNRS, FhG, Philips), which have participated in the FP project, and the assignment of a unique and univocal (second-level) ID code;
3) The identification of the individual researchers that, within each participant, have been involved in each project, with the assignment of a unique ID code to each one of them.

We believe that the upstream implementation of these principles during the process of data entry and data collection should not be too expensive or time-consuming. At the same time, it would provide great benefits for downstream users. First, analytical users would not be forced to allocate most of their time to the rather low value added work of cleaning and standardising data (with a lot of duplicative efforts across different research teams). Second, it would allow carrying out the analysis at a much finer level thus uncovering underlying patterns, which cannot be captured with the presently available data.

In our view, improvements in both information content and data quality within the 'next generation' of DG INFSO's in-house sources should be given high-priority for the policy agenda in preparation of the next FP.

Endnotes

[i] Eustace, Clark "Using Network Analysis to Assess Systemic Impacts of Research", Final Report, DG INFSO, 2009.

[ii] See: "Data Mining and Decision Support for Business Competitiveness: A European Virtual Enterprise", J. Stefan Institute; "ERAnets: Evaluation of Networks of Collaboration between Participants in IST Research and their Evolution to Collaborations in the European Research Area (ERA)", RAND Europe, 2005; "Evaluation of Progress towards a ERA for Information Society Technologies" KITeS-Cespri, 2006; "Networks of Innovation in Information Society: Development and Deployment in Europe", KITeS-Cespri, 2006; and "Trends and Evolution of the EU ICT Research and Deployment Landscape", KITeS-Cespri (in progress) for DG INFSO. In addition, "Science, Technology and Innovation: Network Indicators" (2005); and "Structuring Effects of Community Research: The Impact of the Framework Programme on Research and Technology Development Network Formation" (in progress) for DG Research.

[iii] Our data set includes all FP6 projects funded by DG INFSO and all FP7 projects until project number 266723, call FP7-ICT-2009-C, namely the latest available data at the time of the study. The data were provided by the EU DG INFSO in August 2010.

[iv] According to a previous study on the scientific output of DG INFSO FP6 projects, around 80% of all scientific articles produced by these projects are concentrated in only three scientific fields, namely *computer science* (hardware and architecture, information systems, software engineering, electrical and electronic engineering), *materials science* (applied physics) and *optics.*

[v] Please note that by taking the top *x* percentile of the distribution overcomes the problems associated with the fact that EU countries differ largely in terms of volume of scientific output.

[vi] For more details, http://www.deloitte.co.uk/fast500emea/.

[vii] The 5-year revenue growth rate for these companies ranges from 57940% to 166% (in the 2006 ranking). For details about these companies and the relative annual rankings, see Deloitte (2006), Deloitte (2007), Deloitte (2008) and Deloitte (2009).

[viii] For details on the methodology: http://iri.jrc.ec.europa.eu/reports.htm.

[ix] More details about these indicators and the methodology adopted are reported in the technical report.

[x] A sort of simulation exercise may help understanding the point. Imagine a FP6 project with 21 participants. This project would generate a total of 210 ties. Imagine further that all the 21 organizations participate again in the FP7 (i.e. they are all returning participants), but that due to the decrease in the average project size, 12 of them participate in a project, whereas 9 of them participate in another project. The total number of ties are, respectively, 66 and 36. This means that (210-102)=108 ties are *dissolved*, uniquely because a *large* project has been replaced by two smaller projects.

[xi] Two other papers culminating from the InnoImpact study have undertaken extensive empirical investigation of thèse issues (Kostopoulos, Soderquist, Spanos, Vonortas, 2009; and Spanos and Vonortas, 2011). There are major différences in coverage, however, between those papers and ours hère :

Those two papers use the whole sample of the InnoImpact Survey for both FP5 and FP6 and for all thematic areas of the Framework Programme. In contrast, we are limited to FP6 and to IST projects ;

Our sample is further limited by the identified organizations in the Bocconi database as presented in Section 2 of this report resulting in the small number problem mentioned in the main text ;

No network variables are included in the two papers referenced here.

We recommend that the interested reader refers to the two earlier papers referenced here for further information. Needeless to say, their results are relevant to us to the extent that it can be hypothesized that there are no marked systematic différences between organizations participating in IST projects and the rest.