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Research Networks as Infrastructure for Knowledge Diffusion in European Regions*

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Abstract

This paper concentrates on the role of research network infrastructure in fostering the dissemination of innovation-related knowledge. It examines the structure of collaborative networks and of knowledge transfer between research, innovation and deployment activities in the field of Information and Communication Technology (ICT) for the European Union as a whole and for several European regions. Research networks complement diffusion networks by providing additional links and by increasing the number of the organisations involved in sharing and exchanging knowledge. Two types of actors are key players in these networks: hubs and gatekeepers. Hubs maintain the bulk of ties in the networks also helping the smaller and more isolated members remain connected. Gatekeepers bridge research and diffusion networks. Such organizations naturally offer greater policy leverage in establishing a European knowledge infrastructure. Moreover, strengthened inter-network connectivity among research and diffusion activities (deployment) would raise the effectiveness of European research in terms of accelerating innovation.

1. Introduction

Innovation is a complex socio-economic phenomenon that requires access to technological and financial resources, diverse capabilities and markets. Rarely all these are available in one place, are embodied in one person or are present in a single organisation. Indeed, most innovations appear to occur at the intersection of people, organizations, fields and functions. The role of networks in disseminating information and ideas, providing access to resources, capabilities, and markets, and allowing the combination of different pieces of knowledge has thus become of critical importance for innovation and, by extension, for economic competitiveness. During the past couple of decades the governments of advanced countries have made a strong effort to promote cooperative research. This has been particularly evident within the European Union (EU) (Caloghirou et al., 2002). In the pursuit of a more competitive European economy, the European Commission has built international research networks through the Framework Programmes (FP) on research, technological development and demonstration to create and diffuse knowledge. The research Framework Programmes have provided a systematic process for reaching a number of goals including the integration of European research and technological development across member states; the wide diffusion of knowledge around centres of excellence; the increase in innovation and competitiveness by European-based firms; and the inclusion of peripheral countries and social groups (such as small or gender-based businesses) in European innovative research and development.

Although the share of R&D conducted in Europe that is supported by the Framework Programme is relatively small,¹ this Programme is particularly important for underwriting transnational networks of research collaboration (Roediger-Schluga and Barber, 2006). The network of collaborations built through FP funding over the years can be considered an essential piece of the socio-economic infrastructure supporting the European Research Area (ERA) and the objectives of the “Lisbon Strategy” for turning Europe into a competitive knowledge-intensive region by the end of this decade.

¹ “The principal reference framework for research activities in Europe is national. Funding of the various initiatives of European, Community or intergovernmental scientific and technological cooperation does not exceed 17% of the total public expenditure on European research. The principal instrument used so far in Europe is the European Union’s framework programme for research. In financial terms, however, it accounts for only about 5.4% of the total public effort.” European Commission, 2000, p.7.

This paper concentrates on the role of research network infrastructure in fostering the diffusion of innovation-related knowledge. It examines the structure of collaborative networks and of knowledge transfer between research, innovation and diffusion activities in the field of Information and Communication Technology (ICT) for the European Union as a whole and for several European regions. In particular, it analyses the linkages between the research networks built through the 6th Framework Programme (FP6) funding in the thematic area “Applied IST Research Addressing Major Societal and Economic Challenges”, on the one hand, and the diffusion networks built through EU programmes (eTen, eContent) and regional programmes, on the other. Our findings are empirically-based, applying the concepts of social network analysis and combine both quantitative and qualitative analysis.

We find that research networks represent an important infrastructure for knowledge diffusion and complement regional knowledge dissemination networks by providing net additional links and by increasing the number of the organisations involved in sharing and exchanging knowledge. Two key types of actors are critical for maintaining the linkages within and across networks: hubs and gatekeepers. Hubs maintain the bulk of ties within networks and thus play an important role in keeping smaller and more isolated members connected. Gatekeepers bridge the research and diffusion networks. Hubs and gatekeepers partially overlap and include both research organizations (universities, research institutes) and business firms. Multinational corporations and some small and medium sized firms (SMEs) play key roles in these networks. Multinationals participate in research networks and in large scale projects that link research and diffusion, thus allowing smaller organisations to access critical knowledge, technical or market resources, while SMEs are effective in the deployment of specific applications. A clear policy implication follows from our analysis. If a European knowledge infrastructure is considered important and the connectivity among organizations focusing on research and innovation is a way to strengthen this infrastructure, then the connections between research networks and diffusion networks must be increased and the role of gatekeepers nurtured.

The paper is organised as follows. Section 2 presents a brief literature review concerning the role of networks in bridging research and knowledge dissemination, emphasizing dissemination at the regional level. Section 3 illustrates the analytical methodology and describes the available data. Section 4 reports the results: it characterises the research and

diffusion networks, stresses the role of the key network actors, and investigates the complementarities between research and knowledge diffusion networks. Section 5 concludes and discusses policy implications.

2. Conceptual Framework

A striking feature of industrial innovation today is that only a small minority of firms innovate alone. Adapting to an environment of high uncertainty, global competition, increasing cost and complexity of technical change and fast generation and widespread diffusion of technical knowledge, most firms choose to engage in cooperative relationships. The result is innovations that involve a multitude of organizations. This is especially the case for knowledge-intensive and complex technologies. In the presence of technological development that involves a greater array of product and process systems, subsystems, and components, no single firm can deploy all of the required core capabilities and complementary assets at a reasonable cost. In this context, networks serve as a locus for innovation because, for any network member, it provides more timely access to external knowledge and resources that are otherwise unavailable, it represents a test for internal expertise and learning abilities, and it gives better monitoring and control over fast-moving developments (Powell et al., 1996).

Science, technology and innovation networks are regarded as the emerging organizational mode in environments of rapid technological advance. Therefore success in knowledge-intensive industries depends on organizational learning and commercialization of technologies that take place across various types of networks. Some of the economic, managerial and sociological literature has originally concentrated on alliance networks (e.g. Nohria and Eccles, 1992; Gulati, 1998 and 1999; Vonortas, 1997; Oliver and Ebers, 1998; Nooteboom, 1999; Hagedoorn et al., 2000; Caloghirou et al., 2005). More recently, knowledge networks examined through patents and patent citations and scientific publications have entered impressively into the literature (Jaffe and Trajtenberg, 2002; Balconi et al., 2004; Breschi et al., 2004).

Networks encourage the flow of knowledge related to new ideas, technology, organisations, and markets. A recent stream of theoretical literature has investigated the

relationship between network structure, innovation and diffusion. Cowan and Jonard (2004), for example, develop a simulation model in order to investigate the role of network structure in the process of knowledge creation and diffusion, embodying contributions from sociology (Coleman, 1988; Burt, 1992) and physics (Watts and Strogatz, 1998). In particular, they focus on two structural properties of networks, which are at the centre of debates in sociology and recently also in economics and business studies. Coleman (1988), and many others after him, have argued that being embedded in a very dense, interconnected, “cliquish” network brings benefits by enhancing the trust among individuals and thereby encouraging joint activities and the sharing of tacit and complex knowledge. However, Burt (1992) has argued that when the objective is to access new knowledge, being embedded in a very dense and strongly cohesive network may harm individual learning processes, and that efficiency in accessing knowledge is achieved by placing oneself in structural holes, i.e. by linking previously unconnected parts of the network. The concept of “small world” can be seen as reconciling these two views. Watts and Strogatz (1998) developed a formal model to show that it is possible to build networks that are both “cliquish” (consistent with Coleman’s argument) and characterized by short average distances, consistent with Burt’s view. Cowan and Jonard (2004) apply this framework to the process of creation and diffusion of knowledge. Their main result is that a small world structure permits to reach a greater knowledge growth and to diffuse it more rapidly around the network.

Science, technology and innovation networks have also gained momentum in the policy agenda, including that of the member states of the European Union. They have been perceived as an integral part of the efforts of the EU to develop a European Research Area (ERA) by integrating the systems of member states into a coherent whole (European Commission 2000). The effectiveness of research was linked to the strength of *networking* between research partners and across research disciplines. Creating tight linkages among research units has been viewed as vital to achieving the critical mass, the efficient use of resources, and for realisation of the rich web of connections that are viewed as essential to creativity.

The creation of the ERA is viewed as a first but critical step towards the development of a broad infrastructure for scientific and technological development, i.e. a set of interconnected elements that provide the framework supporting research and diffusion in

Europe. The European Commission (2000) emphasises the definition of virtual infrastructures to connect and facilitate the circulation of information and knowledge, the development of transnational organisational forms, the definition of common standards, and the promotion of shared values.

To this end, the main policy tool has been the research Framework Programme (PETERSON AND SHARP, 1998). Several studies have started to investigate the effectiveness of the Framework Programme in building such an infrastructure (e.g. Larédo 1998; CALOGHIROU ET AL. 2004; Breschi and Cusmano, 2004; Roediger-Schluga and Barber, 2006). FP is argued to affect European research and its capacity to foster innovation. Breschi and Cusmano (2004) and Roediger-Schluga and Barber (2006) focus on R&D networks promoted under the first five FPs. Both studies show that the FP funding schemes support the construction of complex networks which display structural properties that facilitate dissemination. These structural properties appear to be common across FPs despite changes in governance rules. Moreover, it is shown that the FP network has an oligarchic core: there is a significant overlap of participants for consecutive FPs and recurring patterns of collaboration amongst the same organisations. “This core may constitute the backbone of the present European Research Area” (Roediger-Schluga and Barber, 2006, p.36).

FP6 was launched in 2002 with the aim to encourage networking and collaboration across Europe with new instruments and wider scope and budget. In an assessment of Information Society Technologies (IST) in FP6, Breschi et al. (2007) found that the examined IST-RTD programmes played an important role in generating and diffusing knowledge as they managed to attract key industry players and boosted network connectivity. IST-RTD projects attracted global key players and either created networks where there was none before or contributed net significant additions to existing networks.

Existing studies concentrate their attention to the effectiveness of research networks at the European level. A key issue that has been much less analysed refers to how this research network impacts on regional systems and how it interacts with research and diffusion

activities carried out at the regional level.² As Storper (1997) has emphasised, however, one of the most relevant issues in a knowledge-based economy is the tension between globalisation and "territorialisation", the latter referring to the development of knowledge-intensive regional clusters. "The global economy may be thought of as consisting, in important measure, of a mosaic of specialised technology districts [...] The global agents (specially the technology-based oligopolies) [have complex ties with] territorialised relations and conventions upon which they draw and which they help to construct, and without which they cannot function." (Storper, 1997, p.218). Similarly, Bathelt et al. (2004) have indicated the need for complementarities between close and distant interaction in order to foster an effective process of knowledge creation and dissemination and, consequently, for policies able to balance developing of "global pipeline" (e.g. international collaboration) with efforts in generating and promoting local social capital. According to Cooke et al. (1997), an innovative regional cluster is likely to have a dense web of relationships between firms and other organisations both vertically (supply chain) and horizontally (same sector); different kinds of knowledge centres (such as universities, research institutes, technology-transfer agencies); and a governance structure of private business associations, chambers of commerce and public economic development, training and promotion agencies and government departments. A systemic process of innovation within a region requires the interaction of a series of different subsystems. Learning, production and finance act as catalysts of innovation (Cooke, 2001) by defining the conditions under which firms can innovate, by strengthening the capability to harness the benefits from research in a knowledge-based society, and by identifying the way in which interactive innovation can become institutionalised.

The main point of this paper is that there is a major complementarity between the ICT research network built through the Framework Programmes and the diffusion networks built through both dedicated EU funded programs – eTen and eContent – and other national and regional programmes in ICTs that focus more on technology exploitation and development. We claim that the European ICT research network through a variety of

² Regional and research policies in the EU are seen as closely interlinked and, to a certain extent, interdependent. Increased regional cohesion and competitiveness are considered to be partly dependent on the existence of a suitable research infrastructure. See for example http://cordis.europa.eu/fp7/regional_en.html

links and some key actors strategically located across the networks plays the role of infrastructure for the diffusion of knowledge at the regional level. It therefore allows local systems to benefit from, and exploit, research done on a transnational or global scale.

3. Methodology and data

3.1 European level networks

We focus on the innovation and diffusion projects within the technological domains of the Thematic Area “Applied IST Research Addressing Major Societal and Economic Challenges” of FP6.³ This Thematic Area combines cooperative research projects through the Framework Programme and technology diffusion projects through the EU programmes eTen and eContent, on the one hand, with national/regional programmes of technology development, transfer and commercialization, on the other. eTen was designed to help the dissemination of telecommunication networks based services (e-services) with a trans-European dimension. It focused strongly on public services, particularly in areas where Europe has a competitive advantage. eContent was a market-oriented programme which aimed at supporting the production, use and distribution of European digital content and to promote linguistic and cultural diversity in the global networks. We identify organisations participating in FP6, eTen and eContent projects and use them as the initial sample of network analysis (Table 1).

[Table 1 about here]

The basic characteristics of the covered projects and organisations are displayed in Table 2.

[Table 2 about here]

³ Information Society Technologies has been a core investment area in research and technological development since the initiation of the Framework Programmes (FPs) in the early 1980s. This investment had been encapsulated in a host of well known RTD programmes such as ESPRIT I-IV, RACE I-II, ACTS, DELTA, DRIVE, TAP I-II, and AIM. Such programmes and their derivatives were placed under the overall IST thematic priority in FP5 that has continued in the current FP6. The IST thematic priority is also featured prominently in the new FP7.

We build two partnership networks on the basis of this information: a research network and a diffusion network. We assume that if two organisations participate in the same project they are directly linked. Our analysis assumes that each of these links represents a channel of collaboration, knowledge exchange and information spillovers.⁴ We use network analysis software tools (Wasserman and Faust, 1994) to examine network structural properties and their interactions and overlaps, as well as the specific role played by organisations acting as hubs and/or gatekeepers.

3.2 Regions

In order to obtain more detailed information, we have investigated research and diffusion activities within specific regions by complementing the aggregate network analysis mentioned above with a series of in-depth interviews across several regions (NUTS 2 level). We have selected a subset of regions (Table 3) that represent the gamut of science, technology and economic capabilities in Europe. Nine regions have been examined spread in Central Europe (Rhône-Alpes, Bremen, East Wales), Northern Europe (North Jutland⁵, Lansi Suomi), Southern Europe (Attiki, Emilia Romagna, Norte), and a new member state (Malopolskie).

[Table 3 about here]

In these regions we have considered networks supported by instruments more focused on regional development such as the European Structural Funds and other national/regional funds. Our analytical focus has been to identify different patterns of network collaboration and knowledge transfers between research and diffusion activities within these regions. In-depth field interviews regarding projects carried out in the different regions have been conducted with a set of carefully selected organisations in order to support the quantitative network analysis and the better understanding of the linkages between innovation and diffusion processes at the regional level. The interviews add critical information on the value of links and connections within the ERA as provided by the EC-funded activities.

⁴ We consider all the participants in a project having similar roles, i.e. we do not assign any specific role to the prime contactor of the project.

⁵ This region is NUTS 3 level.

We selected two subsets of interviewees per region, one from our aggregate network analysis, which allows us to identify a group of large and small effective producers participating to FP6 and/or eTen and eContent projects, and one from national/regional projects, which allows us to identify organisations that have strong diffusion record. Interviewed regional actors included representatives of companies, of public research centres and/or universities, and of government and quasi-government organisations that facilitate IST diffusion in the selected thematic area and the selected Member State(s) and Region(s). Table 4 illustrates the characteristics of the 62 interviewed organisations - on average 7 per region.

[Table 4 about here]

4. Empirical analysis

This section presents the results of our investigation which combined network analysis on data from EU research and diffusion programmes with information from the interviews carried out within the selected regions. We first illustrate the structural properties of research and diffusion networks at the EU level. We then examine the characteristics of network hubs which represent critical actors in strengthening connectivity within the networks. We subsequently turn to investigate the complementarities between research and diffusion networks and in doing so we place particular emphasis on the role of gatekeeper organisations. Finally, we look at research and diffusion networks and analyse their overlap at the regional level.

4.1 Research and diffusion networks' characteristics at the European level

The differences between the structural properties of the two kinds of networks depend mainly on the size (number of participants) of each network. Research projects tend to have significantly more participants than diffusion projects (Table 5).

[Table 5 about here]

Both networks are highly connected. Most participants are in the largest components, implying that they are connected in some way to each other.⁶ The research network appears, however, to support significantly higher exchange of information compared to the diffusion network given that about 98% of organisations are in the largest component of the former compared to about 71% of organisations in the latter.

More striking differences between the research and the diffusion networks emerge, if the giant *bi-component* is considered. In order for a set of nodes to be classified as a *bi-component* all nodes must be reachable from any other at least via *two* (and not only one) different paths. This feature implies that organisations belonging to a bi-component have a higher probability to receive the information spreading around the network than an organisation belonging to a component. The bi-component of the research network has almost the same size of the largest component (2340 instead of 2373), while the bi-component of the diffusion network is much smaller: 733 organisations instead of 1154. This means that only 63% of the organisations belonging to the giant component have also *another* path connecting to the others. Therefore, in the diffusion network the number of organisations connected to each other is proportionally smaller than in the research network and, even for those who are connected, the connection is weaker. These differences in the connectivity of the two networks reflect both the institutional features and objectives of the two types of programmes, and probably the fact that the diffusion network deals with more focussed activities regarding marketable products.

Information flows more easily in research networks than in diffusion networks. The average distance in the research network is lower than in the diffusion network: any node can reach any other node in the research network in 2.5 steps, on average, compared to 5 steps in the diffusion network. However, diffusion activities are locally more cohesive and dense as suggested by the value of the clustering coefficient which is greater for the diffusion network than the research network.⁷

⁶ More formally, a component is a subpart of a network where there exists at least one *path* (i.e. an alternating sequence of node and edges) linking all its nodes. In other terms, all the nodes belonging to a component have to be reachable at least in one way.

⁷ The clustering coefficient for a node is the proportion of links between the nodes within its neighbourhood divided by the number of links that could possibly exist between them. The clustering coefficient for the whole network is the average of the clustering coefficient for each node and grasps the level of social capital, since it measures how many *direct* partners of a specific organisation collaborate with each other.

Overall, however, and despite such differences, both networks are well structured to be effective and useful as knowledge systems. Their structural properties, i.e. low average distance and high clustering coefficient,⁸ point out that both networks have *small world* properties.

If the research and diffusion networks are considered together (Table 6) (i.e. all the organisations participating in FP6 *and* the organisations participating in eTen and eContent as members of the same network) the giant component⁹ (which includes 3499 organisations (92.7%)) is characterized by an average distance of 3. This means that the overall network is well connected, as each organisation is on average three steps away from any other. In other words, each organization has relatively easy access to information.

[Table 6 about here]

Interestingly, however, the research network and the diffusion network overlap very little. Only 277 organisations¹⁰ participate in both networks. The two networks overlap even less in terms of links: the research and the diffusion networks have only 131 links in common. There are 3011 links among the 277 organisations participating in both networks and these links can depend on a partnership either in a research project or in a diffusion project. 2526 out of 3011 (83.89%) links are related exclusively to research project participations, 354 (11.76%) only to diffusion project participations and only 131 (4.35%) depend on participations in both programmes.

4.1.1 The role of network hubs

Network hubs are key actors within the networks. A hub may be defined as a node with either a large number of connections or a node that is highly influential as a network connector, i.e. one that connects nodes that would otherwise remain unconnected. Hubs

⁸ Here *low average distance* means that the network has the same value of a random network with the same size and density, *high clustering coefficient* means that the network has a value that is much greater than the value of the random network.

⁹ The giant bi-component is slightly smaller: 3150, i.e. the 90% of the size of the giant component.

¹⁰ This includes 11.5% of the organisations participating in the Research Network, 16.9% of the organisations participating in the diffusion network, or 7.3% of the total number of organisations (3774).

have an extremely important role in networks as they facilitate more than other network participants the rapid and effective dissemination of knowledge even to the most peripheral sections of the network. More formally, this definition of a network hub can be captured by two indicators: (i) degree centrality,¹¹ (ii) betweenness centrality.¹² Degree centrality and betweenness centrality have been calculated for all organisations: we have built a synthetic index that ranks organisations according to their performance in terms of both these indicators. Hubs have, then, been defined as the top two percent of the organisations on the basis of this ranking. This share was chosen on the basis of the observation that the top 2% percent of organisations manage 30% of all links.¹³ This procedure has been applied to each network, resulting in the definition of two types of hubs: research hubs (48 organisations from FP6) and diffusion hubs (32 organisations from eTen and eContent).

As anticipated, the *research network* is dominated by higher education and research institutions while the *diffusion network* is dominated by private companies and other organisations¹⁴. It is interesting to notice however that higher education institutions are also active in the diffusion network. Five “other organisations” that appear as hubs in the diffusion network include three city councils, a regional government, and a municipal company.

We also observe key differences in the role of hubs at the local vs. national level, when we compare research and diffusion hubs. Distinguishing between hub linkages with organisations located in the same country and links with organisations located in the same region (NUTS 2), excluding the largest multinational corporations and National Research Centres, and considering only the EU15 countries, we can identify 28 research hubs and

¹¹ Degree centrality is defined as the number of lines incident with a node. In the context of this study, degree centrality is defined as the number of other organisations with which the focal organisation has a relational tie.

¹² Betweenness centrality is defined as the fraction of shortest paths (i.e. the minimum number of lines connecting two nodes) between node pairs that pass through the node of interest. It is a measure of the influence a node has over the spread of information and knowledge through the network. The basic idea is that a node which lies on the information path linking two other nodes is able to exercise a control over the flow of knowledge within the network.

¹³ The two per cent cut-off is obviously arbitrary. However this arbitrariness in the cut-off value is hard to avoid in similar exercises. We considered different values (both higher and lower than two per cent) in order to check for robustness. The main results are not affected. Alternatively, Hubs could have been defined on the basis of threshold values for centrality. This becomes impractical, however, because of the need to compare across different types of networks of different sizes.

¹⁴ Percentages of total organizations are not reported here. They are available upon request.

26 diffusion hubs. Looking at the behaviour of these hubs, we can advance the following points:

- Diffusion hubs act more locally than research hubs.
- National links in research are more than twice as many as national links in diffusion, and regional links in research are more than three times as many as regional links in diffusion.
- Differences between the linkage patterns of different types of hubs emerge. In the research network, private companies are less geographically limited, while the opposite is true for the diffusion network. In the diffusion network, the “other organisations” are those with the most localized links. Their regional links are more than twice the average number. These actors indeed play a key role in diffusion at the regional level. Academic hubs, on the contrary, do not show any differences in the two networks as far as the localisation of their links is concerned.¹⁵

4.1.2 The role of gatekeepers in bridging research and diffusion networks

In our framework, *gatekeepers* are organisations that link the research with the diffusion network. By doing so, they allow others to access information and capabilities developed in other networks and contexts.

[Figure 1 about here]

As seen in Figure 1 gatekeepers are placed between the two networks: they are positioned in both networks. In our analysis, 277 organisations are identified as having this bridging position. Some of these organisations are also hubs, and this has implications in terms of their connectivity within the network. 27 out of 48 (56.2%) of hubs in the research network and 22 out of 32 (68.7%) of hubs in the diffusion network are also gatekeepers. It is worth noticing that 11 organisations are hubs in both networks: they could be classified as the strongest gatekeepers in our sample. We hypothesize that gatekeepers are in a unique position to speed up the process of innovation and technology diffusion, since they work as bridge between the two different networks.

¹⁵ Again, figures with data and numbers are not reported here. They are available upon request.

Higher education institutions and research organisations are more numerous than others as gatekeepers, accounting for about one-third of the total each. However, industrial organisations are also active as gatekeepers (about a quarter of the total) and, within this group, small and medium-sized enterprises (SMEs) play an active role, representing 17% of these bridging organisations.

The variety of different organisational types acting as gatekeepers means that different kinds of knowledge are exchanged and shared across the networks. Our field interviews strongly confirmed this hypothesis. Higher education and research institutes develop and diffuse advanced and frontier knowledge to the network. On the contrary, companies provide links to the market and market information feedbacks so that research can be more focussed on market relevance. A highly functional network would need gatekeepers from the different sectors in order to exchange and integrate different types of information and knowledge. The linkage pattern between the research and the diffusion networks was discussed earlier (Table 6). The important role of gatekeepers in linking research and diffusion networks is highlighted by the fact that one third of all links in both the research network and the diffusion network connect gatekeepers to other organisations in these networks. Simply put, about one third of all links in either network involve the relatively few organizations (277) that bridge the two networks together.

Our field analysis has pointed out that many organisations which are active players in the research networks are often not aware of diffusion opportunities. The opposite also happens frequently: poor links between research and diffusion arise in the case of organisations which are actively involved in diffusion activities, but are not tied into the research network. On the contrary, and as already shown by the network analysis above, gatekeepers are generally well aware of the diffusion opportunities at the international, national as well as and the regional level. They help integrate firm-specific competencies with other organizations which can provide insights and experience, and allow the application of the know-how developed within the research network to specific regional projects. The intermediary function of gatekeepers, deeply integrated in both the research and the diffusion networks, is therefore quite important.

Pushing the issue of complementarities between the research and diffusion networks and the role of gatekeepers in them, we have juxtaposed the research network (FP6) with a network including both the research links and the diffusion links of the same organisations (Table 7). An example is shown in Figure 2.

[Table 7 & Figure 2 about here]

Similarly, we have juxtaposed the diffusion network (eTen, eContent) with a network including both the diffusion links and the research links of the same organisations (Table 8).

[Table 8 about here]

A striking result is how little the research network is affected by the inclusion of the technology diffusion linkages of its participants. All the structural properties barely change (Table 7). In contrast, the structural properties of the diffusion network change significantly when the research links of its participating organisations are introduced (Table 8). The inclusion of the research links raises the degree of connectivity of the diffusion network. For example, both the size of the giant component and the size of the giant bi-component increase significantly. Furthermore, the inclusion of research links reduces the average distance between the participants.

Therefore, an important effect of the IST research network is the enlargement and widening of the number of organisations involved in sharing and exchanging knowledge and information at the regional level and the speeding up of knowledge circulation among the diffusion network organisations.

4.2 Research and diffusion networks in selected regions

In order to examine more in depth the links between the research networks and the diffusion networks, similar analysis has also been carried out for the nine specific regions mentioned earlier (Table 9).

[Table 9 about here]

In general, each of the regional networks in the nine regions has a higher density than the density of the overall network, suggesting that being co-localized makes it more likely to be connected. Attiki and Emilia-Romagna - regions with low capability in science, technology and economy measured in terms of a set of indicators of R&D development, human capital, and industrial structure¹⁶ - have the highest number of organisations participating in IST research and diffusion networks. The latter signals the important role of the European programmes in terms of inclusion and cohesion, and are illustrative examples of the effectiveness of the FP6 in strengthening the connection between research and diffusion.

Fielding large number of organisations, however, does not necessarily imply that the region has a stronger *connection to external hubs*, as Table 10 shows.¹⁷ In fact, it is the presence of hubs in a region (this is the case of Attiki and Rhône-Alpes for research and of Emilia Romagna for diffusion) that increases the connectivity of the region to other external hubs.

[Table 10 about here]

It was reported that the deployment of product- and process-specific knowledge developed by the research network is not always possible due to the lack of sufficient infrastructure to support market introduction. One of the most important issues emerging in the field analysis was the relatively weak linkage pattern between organisations with ideas and regional deployment networks. Notable exceptions exist, of course. An example is the University of Cardiff which actively coordinates a number of local and national activities in addition to EU projects and brings together a lot of local resources.

The complementarity between the two networks is confirmed by the limited overlap between the research and diffusion networks (Table 11).

¹⁶ Source: EUROSTAT, average on 1999-2004. We used the following indicators: GERD per capita, R&D Personnel per inhabitant, Human Resources in Science and Technology, Percentage of total employment in high technology manufacturing, Percentage of total employment in knowledge-intensive services.

¹⁷ The *connections to external hubs* is calculated as the ratio between of existing links among regional organisations and hubs located out of region and the potential ones.

[Table 11 about here]

The overlap between IST projects and structural funds is even smaller: there are no explicit links between the participation in IST networks and the use of structural funds. Structural policy instruments focus mainly on funding projects and general concepts that improve the level of employment in a region, while programmes such as the FP6 prioritise different thematic topics. Given that the priority for regional funds is to help the transition to knowledge society and sustainable development,¹⁸ however, one could argue for stronger linkages across networks to increase knowledge flows.

In general, ICT diffusion activities are not always closely tied to the strategies of the regional governments. There seem to be some differences between the examined Northern European regions, where there is little coordination with regional strategies, and the examined Southern European regions, where coordination activities take place more frequently, in this respect. One relevant finding from the interviews is that large organisations are informed of and exploit regional links, while SMEs are often not aware of the existence of regional strategies for ICT diffusion and do not have resources and capabilities to efficiently use them.

Finally, often organisations are reportedly unaware of any regional strategy that affects them. In many cases they do not have precise information about where they could get assistance with regional diffusion and are not aware of direct links between national and regional networks in deploying ICT products developed within IST research projects. This is probably due to the fact that organisations are aware just of first tier (direct) linkages but are less conscious of second and third tier linkages. That is to say that, while the overall network (research and diffusion) appears to be well connected when looking at the quantitative data, information about diffusion projects and about potential indirect

¹⁸ As Table 11 shows, only in Attiki there is a substantial overlap of organisations and links between research and diffusion networks, and between these networks and structural funds. However, one may recall that Attiki is a capital city region with a major concentration of national industry, quite different from the rest of the regions examined. Furthermore, Greeks are, in relative terms, the most frequent postgraduate students abroad and this helps establish social networks which allows them to make connections within Europe. Finally, structural funds within Greece are strongly supported by government intervention.

linkages with hubs and gatekeepers still remains scarce in the regions, especially for small companies.

5. Conclusions and policy implications

The stronger emphasis on innovation and the quest for balancing supply and demand side effects of technological advancement in Europe implies that both research and diffusion linkages have become a core policy concern and that their analysis deserves intense and deep scrutiny. Both the economic literature and the agenda of European policy makers have recognized for some time now that networks are key means for the development of new knowledge and the diffusion of knowledge into products and processes.

From a policy perspective, the creation of an international infrastructure and interconnected network for science and technology has represented a main concern in the design of the recent Framework Programmes of the European Commission. Some recent empirical contributions have investigated the effectiveness of these programmes and have found positive results. However, much less has been done so far with reference to the relation between European research networks and regional diffusion programmes. The present work aimed at examining the links and complementarities between research and diffusion networks developed through both EU and national/regional funding, using tools from social network analysis and carrying out interviews in a selected number of regions.

Diffusion networks were found to be considerably strengthened by the research networks. Research networks complement regional knowledge dissemination by providing net link additions, presumably allowing many more organisations to be interconnected than would have been the case in their absence, thus supplementing knowledge exchange and broadening the diffusion of information within the network. In particular, the research network increases the number of the organisations that are involved in sharing and exchanging knowledge through the diffusion network. It also speeds up information transmission among its organisations by lowering the average distance among them.

Two (related) types of actors maintain the connections within each network and across the research and the diffusion networks: hubs and gatekeepers.¹⁹ Hub organisations play a critical role in maintaining the ties of the smaller and more isolated members within the networks. They diffuse technological and market information, help define standards for emerging products, and provide demand (applications) for research results. It is the actual presence of hubs in a region that increases the connectivity of the region to others. Gatekeepers bridge the research and diffusion networks, thus helping both to disseminate knowledge of all kinds through various knowledge channels and to provide access to resources and opportunities. The intensity of the activity of individual gatekeepers is remarkable. Even though a relatively small number of organisations fall into this category, they are responsible for one-third of the links in each network (research and diffusion). The vast majority of these links connect gatekeepers and other organisations.

Multinational corporations participate in research networks and in large scale projects that link research and diffusion. In doing so, they allow smaller organisation to access resources such as technical and market knowledge to a larger extent than would have been possible otherwise.

SMEs appear to be important players in diffusion activities. They are deeply rooted in their respective territories and represent very efficient agents when it comes to deploying specific applications and to building relationships with regional authorities.

Our findings have useful policy implications. They support the idea of creating virtual regional innovation systems in order to overcome the tension between global research activities and local diffusion activities. While research across the ERA is highly networked, regional diffusion networks are less interconnected. Moreover, IST research and knowledge diffusion networks are not always strongly connected. It is for these reasons that gatekeeper organisations in the networks play a critical role by providing interconnections across networks. Regions could involve more of these types of organisations in order to bridge the gap between research and knowledge diffusion more effectively and to harness the outcomes from Framework Programme projects. Both

¹⁹ The two sets are not independent: several, but not all, gatekeepers are also hubs.

research and diffusion networks appear to be effective in information dissemination, the latter more so at the regional level.

A key point to notice is that having a large number of organisations in the network does not guarantee extensive linkages to the outside world: the inclusion of hubs among them does. Since the presence of hubs in a region raises disproportionately the connectivity of the region with others, the attraction of such organisations to a region certainly makes sense. Large research and business organisations are critical for bridging research and diffusion as they possess financial, technical, human and locational resources to manage the ensuing complexity. The message here is that regions may find it advantageous to support the presence of such large organisations in their territories. In addition to diffusing technological and market information, helping define standards for emerging products, and providing demand (applications) for research results, the role of such organisations in networks could promote SMEs beyond their limited geographical areas.

At present, however, regional strategies for economic development and ICT diffusion seem relatively unknown to the network participants that we examined. In many cases, organisations focused on the global marketplace in their development process disregarding the regional level. This may be appropriate for frontier research but it is not the most effective way for innovation diffusion. Increased awareness of opportunities should be the first step. In order to promote knowledge diffusion, national governments must play a catalytic role by initiating and supporting mechanisms for inter-regional cooperation and collaboration.

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Tables and Figures

Table 1 – Network Data

	<i>IST RESEARCH Projects</i>	<i>IST DIFFUSION Projects</i>
Description	European network formed by organisations participating in <i>FP6 IST – TAI</i> projects	European network formed by organisations participating in <i>eTen</i> and <i>eContent</i> projects
Data source	Internal EC Database (not publicly available)	Internal EC Database (not publicly available)
Period	First 4 Calls of FP6 2002-2005	eTen: 2000-2005 eContent: 2002-2005

Table 2 – Research and diffusion projects and organisations

	<i>IST RESEARCH Projects</i>	<i>IST DEPLOYMENT Projects</i>
Participants	4198	2008
Projects	249	287
Participants per project	17	7
Organisations	2417	1634
Projects per organisation	1.7	1.2

Table 3 - Selected Regions

East Wales (UK)	Rhône-Alpes (France)	Bremen (Germany)
North Jutland (Denmark)	Lansi Suomi (Finland)	Norte (Portugal)
Attiki (Greece)	Emilia Romagna (Italy)	Malopolskie (Poland)

Table 4 – Interviewed organisations

<i>Type of Organisation</i>	<i>Number (Percent)</i>
Industry (IND)	22 (35.4)
Research Centre (REC)	18 (29.0)
University (HE)	13 (21.0)
Other organisations (OTH)	9 (14.6)
Total	62 (100)

Table 5 - Network characteristics

	<i>IST RESEARCH Network</i>	<i>IST DIFFUSION Network</i>
Number of nodes (organisations)	2417	1634
Number of edges (links)	61686	7422
Network density	0.02	0.006
Giant component	2373	1153
Giant bi-component	2340	733
Average degree	51.04	9.08
Average distance*	2.5	5.08
Max distance*	5	11
Clustering coefficient*	0.0377	0.1292

* These indexes refers to the giant component

Table 6 - Global IST research and diffusion network: structural properties

	<i>IST Network</i>
Number of nodes (organisations)	3774
Number of edges (links)	68977
Network density	0.0097
Giant component	3499
Giant bi-component	3150
Average degree	36.55
Average distance*	3
Max distance*	9
Clustering coefficient*	0.0138

* These indexes refers to the giant component

Table 7 - Research network and diffusion links: structural properties

	<i>IST RESEARCH Network</i>	<i>IST RESEARCH plus DIFFUSION links</i>
Number of nodes (organisations)		2417
Number of edges (links)	61686	62040
Network density	0.02	0.02
Giant component	2373	2375
Giant bi-component	2340	2353
Average degree	51.04	51.34
Average distance*	2.5	2.5
Max distance*	5	6
Clustering coefficient*	0.0377	0.0375

*These indexes refer to the giant component

Table 8 - Diffusion network and research links: structural properties

	<i>IST DIFFUSION Network</i>	<i>IST DIFFUSION plus RESEARCH links</i>
Number of nodes (organisations)		1634
Number of edges (links)	7422	9948
Network density	0.006	0.007
Giant component	1153	1401
Giant bi-component	733	1072
Average degree	9.08	12.17
Average distance*	5.08	3.65
Max distance*	11	9
Clustering coefficient*	0.1292	0.0434

*These indexes refer to the giant component

Table 9 - Regional networks: structural properties

REGION	STE Strength	IST network organisations	Research network		Diffusion network	
			Organisations	Density	Organisations	Density
UK - East Wales	HIGH	2	1	-	1	-
FR - Rhône-Alpes	HIGH	20	12	0.15	9	0.11
DE – Bremen	HIGH	16	10	0.53	9	0.27
DK- North Jutland	HIGH	3	3	0.66	0	-
FI - Lansu Suomi	HIGH	11	10	0.53	1	-
PT- Norte	VERY LOW	22	13	0.35	9	0.11
GR – Attiki	LOW	116	56	0.14	84	0.039
IT -Emilia Romagna	LOW	54	25	0.14	38	0.11

Table 10 - Regional networks: hubs and external connections

REGION	Research network			Diffusion network		
	Organisations	Hubs	Connection to external hubs	Organisations	Hubs	Connection to external hubs
UK – East Wales	1	0	0	1	0	0
FR – Rhône-Alpes	12	2	0.11	9	0	0
DE – Bremen	10	0	0.06	9	0	0.021
DK- N. Jutland	3	0	0.09	0	-	-
FI - Lansu Suomi	10	0	0.075	1	0	0
PT- Norte	13	0	0.089	9	0	0.003
GR – Attiki	56	2	0.11	84	2	0.017
IT –Emilia Romagna	25	0	0.06	38	4	0.026

Table 11 - Overlap between research and diffusion networks by region

REGION	OVERLAP between Research and Diffusion network		OVERLAP between IST networks and structural funds	
	<i>Organisations</i>	<i>Links</i>	<i>Research</i>	<i>Deployment</i>
UK - East Wales	0	-	-	-
FR - Rhône-Alpes	1	0	1	2
DE - Bremen	3	0	1	2
DK - N. Jutland	0	-	0	-
FI - Lansi Suomi	0	-	3	0
PT - Norte	0	-	6	3
GR - Attiki	24	8	17	16
IT -Emilia Romagna	7	0	5	8

Figure 1 - Gatekeepers

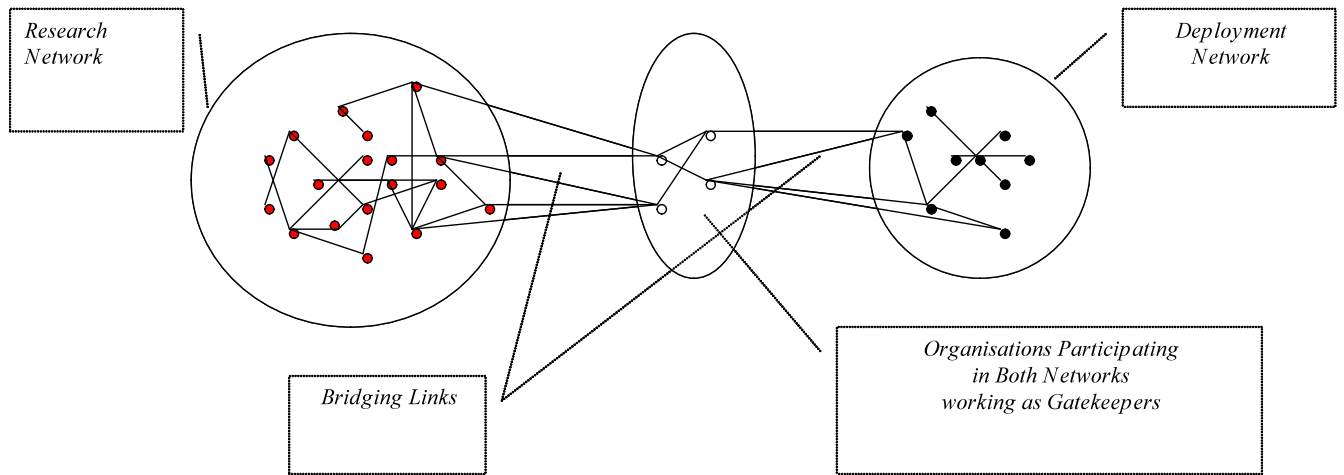


Figure 2 - An example of how the IST Research networks plus DIFFUSION links are built up

