	OPAALS PROJECT Contract n° IST-034824

WP11: Bridging Digital Ecosystems Research to Regional Development and Innovation in the Knowledge Economy

Deliverable 11.11

Structures of knowledge flow and innovation in the Irish Biotechnology industry

Project funded by the European Community under the "Information Society Technology" Programme

Contract Number: IST-034824

Project Acronym: OPAALS

Deliverable N°: 11.6

Due date: M48 (May 2010)

Delivery Date: June 2010

Short Description: This deliverable reports on the results of task 11.6. This involves an investigation of the structures of knowledge flow and innovation in the Irish biotechnology industry. The study was guided by a mixed-methods research design. The structure of the networks was analysed using quantitative social network analysis. The actual knowledge flow through the networks was investigated during interviews with central actors in the biotechnology ecosystem. In addition, the interviews and a workshop were used to discuss the contours and structure of a future biotech DE.

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Partners contributed: NUIM

Made available to: Entire consortium, EC, general public

Versioning		
Version	**Date**	**Name, organization**
1	June 2010	Dr. Chris van Egeraat, Dr. Declan Curran, both NUIM
2	June 2010	Dr. Chris van Egeraat, Dr. Declan Curran, both NUIM

Quality check

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Dependences:

Achievements*	All planned activities for task 11.6 were carried out. In addition, in collaboration with partners at the Fachhochschule Salzburg we developed a network visualisation tool. This was funded by an OPAALS research exchange project.
Work Packages	Extensive contribution to WP 11. The general objective of WP11 was to bridge the necessarily theoretical deliberations surrounding the emerging concept of Digital Ecosystems with the necessarily practical concerns of regional development policy, in the context of the Knowledge Economy, through the capitalisation of research findings in order to generate practical policy learning that is meaningful and workable at the regional scale. Phase three, will be more focused on the concept of territorial adoption of Digital Ecosystems not only at the level of policies - that will however remain an important asset - but also taking in consideration the learning and participative process that lay behind the DE adoption. Task 11.6 is entitled "Structure of knowledge flow and innovation in the knowledge economy: towards the development of a DE for SMEs in the Irish Biotechnology industry (NUIM)". This task aims to build on the findings of OPAALS phase II, T11.1 by studying the requirements and characteristics of a potential Digital Ecosystem in the Irish biotechnology cluster. Towards this, Deliverable 11.11 reports on research that investigated the structure of social networks in the Irish biotechnology sector and the actual knowledge that flows through these networks. The findings have important implications for the roles and contours of a biotech digital ecosystem in Ireland. In addition, the deliverable directly benefit WP10. Notably Deliverable 10.20 which looked at the emulation and testing of OPAALS P2P infrastructure and utilisation. Task 11.6 was supported by an OPAALS research exchange project that involved the testing of the EveSim application developed by the Salzburg partners in a new context. Finally, the work has benefited deliverable D12.13, notably the examination of the role of partner networks in software innovation.

Partners	All partners will benefit from reading this deliverable
Domains	Social Science is the core scientific domain involved in this deliverables. The literature review and material covers various more specific fields, notably innovation studies, spatial economics, industrial economics, economic geography and economic sociology.
Targets	The principle targets of this deliverable include the OPAALS community, other research communities concerned with digital ecosystems, regional development agencies and authorities, industrial associations, associations of SMEs and the various academic communities of the disciplines mentioned above.

Publications*	Van Egeraat, C. and Curran, D. (2010), Social Network Analysis of the Irish Biotech Industry: Implications for Digital Ecosystems. In: Dini, P., *Digital Ecosystems*, Springer (forthcoming) Van Egeraat, C. and Curran, D. (2010) Social Network Analysis of the Irish Biotech Industry: Implications for Digital Ecosystems, *NIRSA Working Paper* No. 55 Van Egeraat, C. and Curran, D. (2010) Social Network Analysis of the Irish Biotechnology Industry: Implications for Digital Business Ecosystems. Paper presented at The Third International OPAALS Conference on Digital Ecosystems, Aracaju, Brazil, March 2010. Van Egeraat, C. (2009) Digital Ecosystems Explained. Paper presented at the workshop Planning a Digital Ecosystem for the Biotech Industry, Dublin Regional Authority, 3 November 2009. Van Egeraat, C. and Curran, D. (2009), Knowledge Flows and Networks in the Irish Biotech Industry. Paper presented at the workshop Planning a Digital Ecosystem for the Biotech Industry, Dublin Regional Authority, 3 November 2009. Van Egeraat, C. and Curran, D. (2010), Socio-Spatial Foundations of Knowledge Flow in the Irish Biotechnology Industry and the Role of Digital Ecosystems, Centre for Innovation and Structural Change, Galway, January 2010 Van Egeraat, C. and Curran, D. (2010), Knowledge flow in the Irish biotech industry. Are social networks exploited?

	Paper accepted for presentation at the *DIME workshop on Industrial Dynamics and Economic Geography,* Utrecht, the Netherlands 5-7 September 2010
PhD Students*	No PhD students were involved.
Outstanding features*	The current understanding of the social and spatial foundations of innovation processes is limited. This deliverable provides an important contribution to this understanding. In particular the deliverable highlights the fact that many of the networks that tend to be analysed through social network analysis are only suggestive of knowledge flow. This research project also investigates the extent to which the social networks are actually exploited for knowledge flow, as well as the type of knowledge that flows through the networks. In addition, it provides important insights into the spatiality of the knowledge flow and the spatial scale of the relevant ecosystem. The research also provides valuable insights into the implications of these findings for the role and contours of a biotech digital ecosystems in Ireland.
Disciplinary domains of authors*	Dr. Chris van Egeraat, National Institute for Regional and Spatial Analysis and Department of Geography, NUI Maynooth Dr. Declan Curran, National Institute for Regional and Spatial Analysis, NUI Maynooth

The information marked with an asterisk (*) is provided in order to address Recommendation n. 4 from the Year 2 review report

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EXECUTIVE SUMMARY

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This Deliverable reports the results of Task 11.6 of the third phase of the OPAALS Project. Task 11.6 is part of WP11, which focuses on bridging the gap between Digital Ecosystems research and Regional Development and Innovation in the Knowledge Economy. The objective of WP11 was to bring together the theoretical deliberations surrounding the Digital ecosystems concept and the practical concerns of regional development policy, through the capitalisation of research findings in order to generate practical policy learning that is meaningful and workable at the regional scale. Compared to phase II, WP11 in phase III was to be more focused on the concept of territorial adoption of Digital Ecosystems.

A Digital Ecosystem (DE) is a self-organising digital infrastructure established with the aim of creating a digital environment for networked organizations which is capable of supporting co-operation, knowledge sharing, the development of open and adaptive technologies and evolutionary business models (Nachira et al., 2007). Digital Ecosystems provide structures of communication and collaboration that can facilitate collective learning, knowledge flow and innovation across SMEs and other actors.

In order to understand sustainable digital ecosystems of SMEs and the contribution they could make to competitiveness of SMEs and regional development, we need to understand in depth the processes of knowledge flow and innovation. Task 11.6 set out to explore and explain the structures of knowledge flow and innovation among SMEs in the Irish biotech sector. In particular, the study addressed three main research questions: (1) What are the structural characteristics of knowledge and innovation networks in the Irish biotech sector and are these conducive to knowledge flow? (2) Are these networks exploited for local knowledge flow (3) What does this mean for the role of a biotech digital ecosystem and its contours?

The research design involved a mixed methodology, involving social network analysis, interviews and a focus group meeting. Social network analysis was applied to investigate the extent and structure of different types of networks and their related knowledge flow in the biotech industry. In addition, interviews were conducted with biotech sector actors and experts to (1) obtain more detailed insights into the character of the knowledge flow and (2) distil the implications of the findings for the roles and contours of a biotech digital ecosystem. Finally a focus group meeting was organised to discuss the research findings and solicit the ideas of the biotech community.

The first research question was addressed through quantitative social network analysis. The small world analysis of the informal network of company directors reveals that this network is characterised by short path lengths and high clustering. This type of structure is conducive to knowledge flow. The formal network of researchers (patent data) is also characterised by high clustering and short path lengths. However, in this instance the company network is noticeably less clustered via patents than it was through directors. This indicates that that this formal network of researchers is conducive to knowledge flow although relatively less than the

informal network of company directors. The formal network of spin-off companies (emanating from both biotech companies and universities) exhibits no small world characteristics, which would indicate that the structure of this network is not conducive to knowledge flow.

The network data was also used to explore a number of spatial aspects of the biotechnology networks. The formal network of researchers was shown to have both national and global dimensions. These formal network data support the view that while the investigator network has a strong national component, the Dublin region, and even Ireland as a whole, should not be treated as "an isolated island of innovation". The informal network of company directors is far less global in character. This should however not be generalised to other informal networks in the biotech industry. It is true that the membership of most national professional and industrial organisations is nearly entirely national. However, the interviews undertaken in this study demonstrate that other informal networks such as the professional networks of individuals, the epistemic community and network of university alumni include a large international component.

Although a large part of the Irish biotech industry is concentrated in the greater Dublin Area, the directorship network is not bounded by the city-regional scale. Many directors of companies in Dublin have links with companies outside the city-region. Therefore, from a directorship network perspective, the relevant scale of the biotech ecosystem is national, rather than city-regional.

The geography of the spin-off processes is surprising. Existing theory and empirical accounts generally suggest that spin-off firms locate in the same region as the spinner firm, representing an important mechanism for localised industrial agglomeration and clustering. In the Irish biotech industry, although many of the spin-offs of Dublin-based institutions/firms established themselves in Dublin, a relatively large number of firms that spun off institutions/firms located outside Dublin, ended up in different regions, notably in Dublin. Therefore, although a large part of the industry is concentrated in Dublin, we would argue that from a spin-off network perspective, the relevant scale of the biotech ecosystem is again national, rather than city-regional.

The social network analysis provides insights into the structure of the networks and their ability to support knowledge flow. However, the structures are only suggestive of knowledge flow. It remains unclear how much knowledge flows through the links and how far the knowledge actually flows through the network. It is therefore important to investigate what actually flows across the links (Grabher, 2006) – the extent to which the networks are exploited.

To answer this second research question, interviews were conducted with members of the various networks. The interviews show that the three particular networks under consideration are poorly exploited, although to different extents. With respect to the network of investigators (patents) we found no evidence of companies obtaining knowledge from either the directly or indirectly linked companies. The network of directors involves a greater amount of knowledge flow. Interestingly, apart from one case, the flows generally do not involve technical knowledge concerning the directly linked firms.

Most interviewees stated that their firms had received valuable general business and know-who type knowledge from their directors, including from those with multiple directorships. However, all but one of the interviewees argued that the link with the directorship network was of limited relevance. The knowledge generally involves the embodied knowledge of the director. It is difficult to assess the role of the directorship network for the accumulation of this embodied knowledge inherent in the director. What is clear though is that, for the focal firms themselves, the directorship network plays a relatively limited role in the identification of, and/or introduction to, relevant actors in the Irish market. The interviews show that the directorship network is merely one, relatively less important, network in a broader set of informal network relations connecting companies.

Interestingly, directorship networks do play a more important role at the international scale. A number of the interviewed companies have corporate interlocks with firms outside of Ireland and these are frequently used to obtain information about firms or markets abroad.

The interviews provided evidence of more substantial knowledge exchange in the third network, the network of spin-offs. The more formal spin-offs in the sample involved both technical and know who / market type knowledge and in both cases some of the knowledge was considered relatively important for the innovative performance of the firm. The less formal spin-off relations in the sample tend to involve lower levels of knowledge flow, and the flow tends to be limited to know-who and market related knowledge of limited strategic importance.

Apart from the firms linked by the three networks, the interviewed companies did obtain knowledge from other local firms. With respect to technical advice, all interviewed companies had been in contact with between three and nine other Irish companies/institutions. Universities were the main sources for technical knowledge. However, in general, the majority of cases involved very limited technical advice or knowledge flow. Most strategic links tend to involve universities.

Although some of these contacts started with a “cold call”, we found evidence of informal networks facilitating the identification of the relevant actors. However, the number of instances of companies intentionally consulting other local companies for local know-who/business type knowledge, was relatively small. The relatively low level of intentional local know-who exchange is due to the fact that companies are relatively well informed about the local actors. This is not to say that networks play no role. The level of personally embedded know-who type knowledge is, in fact, largely a result of long term participation in local networks. In addition, the informal networks are strongly exploited for obtaining knowledge about actors in other countries.

A combination of, mainly informal, personal networks are at play, including professional networks of the individuals, student networks and social networks. Most important are the personal professional networks, built up over years, linking former and current colleagues and commercial contacts. Another important network is formed by university alumni. Apart from the personal networks, an increasingly important set of networks is created by the various industrial or research support agencies, including IDA, Enterprise Ireland, university tech transfer offices, Science Foundation Ireland, etc.

The findings are surprising, at least at first glance. The formal network of spin-offs turns out to be the most intensely exploited, notably for technical knowledge flow. This is the network that was considered least conducive to knowledge flow on the basis of social network analysis. The explanation for this apparent contradiction is that the knowledge flow tends to be contained between the spinner and the spin-off firm. That is, the level of diffusion to the broader industry is limited.

On the other hand, the network that was suggested to be most conducive to knowledge flow according to the social network analysis exercise, the informal network of company directors, appears to be strongly under-exploited - both for technical and know-who type knowledge flow. Two points need to be made here: First, the directorship network should not be interpreted as a separate network, functioning independently of all other networks. Rather it is part of a large integrated set of partly overlapping informal networks linking the Irish biotechnology firms. It is clear, though, that the directorship network is a relatively unimportant element in the overall informal network constellation. Other informal networks play a far greater role in knowledge flow.

Secondly, the fact that most (established) biotech companies make a lower than expected use of the informal networks for the active or intentional search for know-who type knowledge concerning the local industry does not mean that these networks are not exploited or not valuable. The Irish biotech industry is small and it is precisely due to the long-term participation in the local informal networks that most established actors are, and remain, (passively) informed about the relevant players in the local industry. In addition, the interviews do suggest that less established firms do rely more strongly on their informal networks for know-who type knowledge and introductions to local actors. Finally, the informal networks do play a significant role in (intentionally) obtaining know-who type knowledge about non-local actors.

The insights into the structural characteristics of the knowledge and innovation networks, and the actual level of knowledge flow of the Irish biotechnology sector yield important lessons regarding the roles and contours of a biotech DE. Based on these insights we can confirm many of the ideas expressed in earlier OPAALS Deliverables on this topic, as well as add a number of further ideas:

- The results confirm that, rather than focussing on individual formal networks, the biotech DE should involve the entire social worlds of firms - the entire constellation of informal social networks, including professional networks of individuals, university alumni, and social networks.
- A biotech DE can play a valuable role in facilitating the flow of know-who and business/market type knowledge related to Ireland, particularly benefitting new, less established, firms. It will be of limited benefit to established firms. This can involve the exploitation of existing informal network links and the stimulation of new network links.
- A biotech DE can play a particularly valuable role in stimulating the flow of know-how and business/market type knowledge related to foreign locations. This can also involve the exploitation of existing informal network links and the stimulation of new network links.

- Existing informal networks in the biotech industry involve limited technical knowledge flow and diffusion, mainly due to efforts to protect firm-specific knowledge and intellectual property. There is however scope to better exploit the informal network for the flow of non-sensitive technological knowledge.
- The central importance of universities as the principal source of technical knowledge suggests that a biotech DE should specifically aim to facilitate the development and exploitation of formal and informal networks involving these universities.
- The analysis of the various networks suggests that the Irish biotech ecosystem functions at a national scale. Although many firms are spatially concentrated in the Dublin area, the firm are part of a national ecosystem. A biotech DE in Ireland should therefore be structured on a national, rather than a regional scale

To further distil these lessons and ideas for actual biotech applications, interviews were conducted with members of the biotech community and industry experts and a focus group meeting was organised to solicit the ideas of the biotech community. Based on the results of the network analysis, the interviews and the focus group meeting, we believe that the following applications have the greatest potential to kick-start a biotech DE in Ireland:

- A forum for regional actors (in universities; research institutions and private enterprise) to consult each other on a reciprocal basis about the location of (regional and extra-regional) actors, sources of knowledge and relevant intellectual property. This forum would involve a network visualisation tool which identifies national and international connections of actors. This idea is illustrated in the next section.
- A regionally-based science forum for biotechnology scientists and technicians. Here biotechnology scientists and technicians in companies and universities could ask for advice about, and interactively discuss, scientific and technical problems.
- A biotechnology sector-dedicated electronic interactive labour exchange, matching skilled people to jobs.
- A directory tool, providing information about and promoting regional actors, as well as promoting Ireland as a biotech region.

Building on these research findings, a further OPAALS research exchange project contributed to the development of a tool that could become part of the suggested forum for regional actors – a network visualisation tool. This visualisation tool could play an important role in identifying connections of potential partners in Ireland and abroad. This could allow actors to identify common contacts who may provide helpful introductions.

1 INTRODUCTION

This Deliverable reports the results of Task 11.6 of the third phase of the OPAALS Project. Task 11.6 is part of WP11, which focuses on bridging the gap between Digital Ecosystems research and Regional Development and Innovation in the Knowledge Economy. The objective of WP11 was to bring together the theoretical deliberations surrounding the Digital ecosystems concept and the practical concerns of regional development policy, through the capitalisation of research findings in order to generate practical policy learning that is meaningful and workable at the regional scale. Compared to phase II, WP11 in phase III was to be more focused on the concept of territorial adoption of Digital Ecosystems.

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The DE and its uses fits well with recent work in studies of innovation which emphasis the collective, collaborative processes that underlie innovation. This research details how innovation processes are becoming increasingly complex, involving different types of knowledge. Individual firms can no longer rely on their internal sources of knowledge alone. Instead additional knowledge needs to be accessed from external sources. These trends have been characterised as a transition towards ‘open innovation’ (Chesbrough, 2003) and ‘distributed knowledge networks’ (Asheim, Boschma and Cooke, 2007)

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Section two of this report presents the theories and themes on which the study focuses. This is followed by an outline of the methodology in Section three. Section four introduces the Irish biotech sector. Next, Section five presents the findings regarding the structure of three knowledge and innovation networks in the Irish biotech industry. Section six subsequently analyses the extent to which the networks are actually exploited. Section seven discusses the implications of the findings for the Irish biotech digital ecosystem, partly based on interview and workshop findings. A number of applications to initiate a biotech DE are suggested. One of these applications is presented in Section eight. It concerns a biotech network visualisation tool, developed during an OPAALS research exchange project in collaboration with Fachhochshule Salzburg. The report ends with conclusions.

At this point we would like to thank all the people at the various firms and institutions who have co-operated with this research. In particular, we would like to thank Maria Ginnity and Mark Faherty (Forfás), Dr. Keith O'Neill (Enterprise Ireland) and Patricia Potter (Dublin Regional Authority) for supporting and facilitating this research. In addition we thank the interviewees and seminar participants for their information and ideas. A special thanks to our partners at the The Fachhochschule Salzburg - Professor Thomas Heistracher, Thomas Kurz, Raimund Eder and Christoph Reucker – for the enjoyable collaboration in developing the network visualisation tool. Also to the two internal reviewers - Fernando Colugnati, IPTI Brazil and Lorraine Morgan, UL Ireland – for their constructive comments. Finally we would like to thank our friends at the Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Lund University – in particular Jerker Moodysson and Bjorn Asheim – for their advice and providing us their interview tools.

2 THEORETICAL FRAMEWORK

This section starts with a discussion of the economic ecosystem concept and the fact that most economic ecosystems have territorial aspects. The following section, 2.2, introduces related territorial ecosystem concepts and shows how relations and networks form a core part of such conceptualisations. Section 2.3 is devoted to the network concept. It starts with a brief overview of the main traditions in network theory, focussing on social network analysis. This is followed by an outline of the main conceptual devices or tools of the social network analysis tradition. The next sub-section introduces network typologies, notably the distinction between formal and informal networks that we propose have different structures. The final sub-section discusses and problematises the concept of network spatiality.

2.1 Digital Business Ecosystems

Recent studies of innovation emphasise the collective, collaborative processes that underlie innovation. This work details how innovation processes are becoming increasingly complex. Individual firms can no longer rely on their internal sources of knowledge alone. Instead additional knowledge needs to be accessed from external sources. The situation of slowly changing networks of organisations will be replaced by more fluid, amorphous and transitory structures based on alliances, partnerships and collaborations. These trends have been characterised as a transition towards 'open innovation' (Chesbrough, 2003) and 'distributed knowledge networks' (Asheim, Boschma and Cooke, 2007).

Knowledge economies can be thought of as ecosystems characterised by open innovation processes. The term ecosystem originated in biology and refers to the way the various organisms in a particular area interact with each other and with the natural environment so as to create a balanced, stable, system. In the same way, knowledge economies can be understood of as assemblages of interdependent institutions in which the welfare of the component organisms is dependent on the interactions between them. A business ecosystem can be understood as an economic community made up of individuals, firms and organisations that interact with each other to their mutual benefit. Economic or business ecosystems tend to be organised on a territorial basis (Malecki and Moriset, 2008) as expressed in related concepts such as clusters (Porter, 1990) and regional systems of innovation (Cooke, 2001).

Ecosystems tend to evolve towards an optimum state due to gradual adaptation. The evolution is accelerated by the promotion of higher and more efficient levels of knowledge flow/sharing. Towards this, *Digital* ecosystems seek to exploit the benefits of new ICTs in terms of enhanced information and knowledge flow.

The specific Digital Ecosystem (DE) put forward by the OPAALS Research Consortium is a self-organising digital infrastructure established with the aim of creating a digital environment for networked organizations which is capable of supporting co-operation, knowledge sharing, the development of open and adaptive technologies and evolutionary business models (Nachira et al., 2007). The Digital Ecosystem concept promoted by the OPAALS Community distinguishes itself on the

basis of its open source and peer-to-peer nature – a loosely coupled server system. The Digital Ecosystem provides structures of communication and collaboration that can facilitate collective learning, knowledge flow and innovation across SMEs and other actors. The Digital Ecosystem is more than software and infrastructure. It provides an IT architecture as well as an economic model and a shared enterprise. In addition, it provides an integrated approach to economic development.

2.2 Related territorial innovation concepts

Economic ecosystems tend to be organised on a territorial basis as expressed in related concept such as clusters and regional systems of innovation. Since the mid-1980s territorial concepts such as spatial clustering, agglomeration, industrial district and national/regional system of innovation have attracted much interest from academics and policy-makers concerned with regional/national economic development. Indeed, innovative clusters have become a policy panacea for many governments and international agencies such as the OECD that see clusters as drivers for regional and national competitiveness and growth.

Several cluster advantages may underpin this enhanced competitiveness. One stream of the academic literature has focussed on traditional agglomeration economies, notably the external economies of scale and efficiencies in the supply of inputs, services and the labour market. However, empirical research does not always find evidence for extensive local production linkages between firms in a sector, thereby undermining at least part of the argument. Another stream of that cluster literature has focussed on the knowledge flows and knowledge spillovers between local actors that are believed to support the process of localised learning and innovation. Contributions to a knowledge-based theory of spatial clustering typically interpret learning and innovation as interactive processes that involve an exchange of knowledge between firms and other actors (including universities and other research institutions). The idea is that proximity in local clusters can lead to dense networks of communication and information linkages that support both intentional and unintentional knowledge flows.

Although definitions vary and great overlap exists between the various territorial conceptualisations, they should not be conflated. (Coenen et al, 2006; Asheim et al, 2006). The different concepts are informed by rather different theoretical perspectives that emphasise different drivers for localisation and sometimes different types of business concentrations.

The concept of clustering is defined in many different ways, depending on the academic field and/or school of thought (Ingstrup et al., 2009; Martin and Sunley, 2003). One of the most influential theoretical schools of clustering has emanated from the work of Michael Porter. Porter (1998) defines clusters as geographical concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, associated institutions (for example universities, standards agencies, and trade associations) in particular fields that compete but also co-operate. He stresses the role of interconnections between firms and other actors and recognises that such interconnections involve relationships or networks that produce benefits for

these firms. (Asheim et al, 2006). However, the theoretical unit of interest in understanding economic growth remains the firm, not the network. (Edquist, 2006)

The system of innovation school takes a rather different perspective. A system of innovation can be defined as the determinants of innovation processes. This includes all the important economic, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations (Edquist, 2005). In principle, such systems can cover several industrial sectors although some have demonstrated the importance of sectoral systems of innovation in shaping innovation and growth, (Lundvall et al, 2002; Kim and Nelson, 2000; Malerba, 2003). Much technological learning occurs around specific products (Storper, 1997) and this 'product based technological learning' becomes the basis of sectoral systems. The key products within a sector become the focus of learning among a diverse group of economic actors – firms, workers, academics, research policy makers and others. These become crucial constitutive elements of 'business ecosystems', facilitating and shaping knowledge flows. The concept was first linked to the national scale. Such national systems of innovation concern "the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state." (Lundvall, 1992). Since then, researchers have applied the concept of regional systems of innovations (Cooke, 2001)

The system of innovation approach employs a historical and evolutionary perspective. The process of innovation develops over time and is influenced by many factors and feedback processes. The approach emphasizes interdependence. Firms do not innovate in isolation but interact with others organizations. Even stronger than the Porterian School, the system of innovation approach emphasises that processes are not only influenced by the components of the system but also by the relations between them. Attention focuses on network theories of innovation and the emergence of regional innovation systems, localised interactive learning and local entrepreneurial milieu. For this reason the approach is heavily directed towards groupings of high-tech industries, including biotechnology (Edquist, 2006)

One of the common elements in all approaches and definitions of clustering is the concept relations and networks. These relations and networks are believed to contribute to the development of the cluster and the competitiveness of the firms.

2.3 Networks

2.3.1 Dominant traditions in network theory

Current territorial economic development concepts generally recognise that networks are an important aspect of innovation and clustering processes. Networks are seen as crucial for understanding the dynamics of clusters (Ingstrup et al. 2009). Network theory and analysis can therefore lead to a better understanding of innovation and clustering processes (Ter Wal and Boschma, 2008).

The roots of the network concept and network theory go back to the end of the 19^{th} century (Grabher, 2006). In sociology, anthropology, and psychology, network

analysis was initially employed in a range of empirical context. For a long time surprisingly little attention was devoted to the role of networks in economic activity but this has changed drastically in more recent times. Since the early 1990s an increasing body of economists, economic sociologists and economic geographers have been focussing on the role of networks in economic activity, innovation and regional development. In broad terms a network can be defined as a set of actors linked through a specific type of connections (Grabher, 2006). In this paper we focus on business/innovation networks.

Grabher (2006) identifies two dominant approaches to, or traditions in, network theory and analysis: the social network analysis and the governance approach. Social network analysis is based on the assumption of the importance of relationships among interacting units or actors and that units don't act independently but influence each other. Relational ties between actors are viewed as channels for transfer or flow of resources. The unit of analysis is not the individual, but an entity consisting of a collection of individuals and the linkages among them. The social network approach provides a precise way to define important social concepts, a theoretical alternative to the assumption of independent social actors and a framework for testing theories about structured social relationships (Wasserman and Faust, 1994). As an analytical tool, social network analysis provides explicit formal statements and measures of social structural properties. These tools facilitate the conceptualisation of the interdependencies of behaviour and processes in networks. Structural properties are formally conceptualised in terms of nodes and linkages and captured in "sociograms". The tradition of social network analysis has developed a range of conceptual devices that can facilitate an analysis of regional business ecosystems. These will be discussed in the following section.

The second approach identified by Grabher (2006), the governance approach, is founded on Granovetter's (1985) relational concept of embeddedness. The approach focuses on the institutional mechanisms by which networks are initiated and co-ordinated. In contrast to the social network tradition, this approach concentrates on the particular institutional and social contexts in which actors are embedded. Rather than the formal structure of networks, the approach analyses the specific content of networks.

2.3.2 Conceptual devises of social network analysis

The social network analysis tradition offers a range of conceptual devices for analysing regional business or innovation ecosystems. Based mainly on Grabher's (2006) overview, this section discusses some of these. The actual measures and techniques will be described in more detail in the methodology section.

Structural Equivalence.

The structural equivalence concept can be applied in the analysis of the diffusion of innovations. Structural equivalence occurs when two actors occupy similar positions in a social system by having identical ties with other network members. Structural equivalence predicts that actors identically positioned in the flow of influential communication will use each other as a frame of reference for subjective judgements even if they have no direct communication. It is not through the intensive exchange between network members but through the perception of the proper action for an

occupant of a specific position in the network that innovation diffusion is primarily driven. In this perspective, innovation is stimulated by social pressure of mutual comparison, rather than smoothly diffused through dense local relationships. From this perspective the adoption of a digital business ecosystem platform by the Irish biotechnology industry will be facilitated by structural equivalence in the network rather than by cohesion and dense local relationships

Structural Holes

This structural holes concept focuses on the network position of individual actors. Actors who connect two others, previously unknown to each other, bridge a structural hole. These bridges represent ties between networks that otherwise would remain separated. Such ties provide opportunities of arbitrage. Actors close to structural holes are in a good position to gain ideas since they enjoy more opportunities to select alternative ways of thinking. Rather than interpreting networks as webs of trustful relationships, the idea is that actors that bridge structural holes can exploit this position through strategic play. The identification and awareness of structural holes and actors that bridge these is informative for potential roles of a digital biotech ecosystem as well as the implementation and diffusion of the DE platform.

Strong and Weak Ties

Weak ties score low with regard to the amount of time, emotional intensity, intimacy and reciprocal services. Counter-intuitively, information and knowledge can reach more actors and traverse greater social distance when passed through such weak ties. In addition, the knowledge that flows through strong ties is often of less strategic value. It is through weak ties that link different social groups that the more strategic information becomes available. Marginal actors and outsiders are believed to play a crucial role in the initial stages of information diffusion.

Small Worlds

Small world analysis is concerned with the density and reach of ties rather than with the strength of ties. A small world is a network in which many dense clusters of actors are spanned by relationships that act as conduits of control and information (Kogut and Walker, 2001). In networks with small world characteristics actors can "reach" most other actors in a relatively small number of relational moves. Small world analysis has been productively applied in the context of biotech clusters. Casper and Murray (2005) for example, reported important differences in the structure of the networks in the Cambridge and Munich biotech clusters. Small world analysis has important application in the context of regional biotech digital ecosystems. Knowledge will flow most efficiently in biotech ecosystems with small world characteristics. Where small world characteristics are absent, these can be created by adding a relatively small number of remote links to the network where the level of local clustering is already high.

The social network analysis tradition can provide great conceptual and theoretical insight into network structures. These insights are important to studies of innovation and territorial development because the structures are suggestive of efficient knowledge flow. However, it often remain unclear how much knowledge flows through the links and how far the knowledge travels through the network (Dahl and Pedersen, 2004). In addition, some knowledge is more strategic than other. It is therefore important that we know what flows across the links (Grabher, 2006). This is, of course, partly dependent on the type of actors in the network.

2.3.3 Types of networks and knowledge exchange

Moving away for a moment from the formal theoretical constructs of the SNA, a range of network forms and types can be identified (see, for example, Grabher, 2006). For the current research project the authors make a basic distinction between formal and informal networks[1] (facilitating formal and informal knowledge exchange). Formal networks are configured as inter-organisational alliances while informal networks are based on inter-personal ties. In our view, formal networks include both the longer-term strategic networks based on strategic alliances and joint ventures, as well as the shorter term project networks distinguished by Grabher (2006). In formal networks firms or institutions are linked in their totality, e.g. via joint research projects or buyer-supplier agreements.

In informal networks, the connected persons principally represent themselves. Because the persons are employed by firms and institutions, the links between these persons indirectly also link the institutions, providing a pipeline for (informal) information flow between these institutions. A large variety of informal networks exist including networks of former students, professional networks, networks of friends, members of sport clubs, networks of corporate board members, and so forth.
Informal networks can develop on the back of formal business activity, as is the case with networks of former colleagues or former business relations that have developed a friendship. However, the characteristic of such informal networks is that the network is no longer based on these (former) formal relations. Informal networks have different levels of organisation or institutionalisation. Some professional networks (informal from the firms' point of view) can be strongly institutionalised while other networks, for example those based on friendship are virtually unorganised.

In the current study formal networks are seen as pipelines for formal knowledge exchange while informal networks are linked to informal knowledge exchange. The informal/formal knowledge flow distinction should not be confused with the distinction between intentional and unintentional knowledge flow (see also Van Egeraat et al, 2009). Unintentional interaction (Oerlemans and Meeus, 2005) within a group of actors involves the acts of observation and comparison (Malmberg and Maskell, 2002). The distinction between intentional and unintentional knowledge flow is closely related to the concept of "buzz" that is rapidly gaining popularity (Bathelt *et al.*, 2004; Storper and Venables, 2004; Gertler and Wolfe, 2006; Gertler, 2008; Moodysson, 2008). Buzz refers to "non-deliberate knowledge and information exchange propensities" (Asheim et al., 2006, p. 214) and "is predominantly about knowledge spillovers (*Ibid.*, p. 216). Informal knowledge flow can be both intentional, as in the case of an engineer who phones a friend in a different company for technical advice, and unintentional, as in the case of an individual that hears about a new technology during a social gathering.

The current study focuses on three different networks in the Irish biotechnology, the formal network of researchers and related companies, the informal network of

[1] The formal vs. informal distinction is closely related to the distinction between structural social capital and relational social capital as recognised by Nahapiet and Ghoshal, (1998) and applied in the context of the Cambridge biotech industry by Myint and Vyakarnam (2004).

company directors and the formal network of spin-off companies. Formal networks of researchers have been the subject of many previous studies, notably in the context of the biotech industry (Owen-Smith and Powell, 2004 and 2006; Coenen, et al., 2006; Moodysson and Jonsson, 2007). Much of this research is based on patent-data, although some studies are using survey data providing more detailed information about the type of knowledge flows. Networks of company directors were investigated as a case of informal networks. Directors of biotech companies tend to hold directorship on different corporate boards. Where this concerns biotech companies, the various links can be taken to represent a conduit of informal knowledge flow between the respective companies. Myint and Vyakarnam (2004) and Myint et al. (2005) investigated the corporate board interlocks in the Cambridge biotech industry and reported the influential role of a select number of 'mini clusters' in the local network. The study findings support the salience of both structural (formal links) and relational (informal links) social capital. Studies of corporate interlocks in other contexts include Kogut and Walker (2001) and Davis (2003)

Finally, many firms start as spin-offs from a different firm or institution.[2] Generally the new company is based on knowledge developed at the parent company, the parent company tends to offer different kinds of support, and semi-formal links tend to be maintained. Spin-off networks can therefore involve important knowledge flows. Spin-off networks and family trees have been analysed in the context of the biotech industry (Myint et al., 2005) and high-tech sectors (Mayer, 2009). The object of these studies was to understand the evolution of clusters and the importance of spin-off processes and serial entrepreneurship, rather than knowledge flow per se. However, Myint et al. (2005) does suggest that the serial entrepreneurs are important foci for knowledge flow in the network. It is important, though, not to confuse spin-off networks with networks constructed by serial entrepreneurs.

2.3.4 Spatiality of Networks

Rather than treating regional networks as a distinct type of network (Grabher, 2006) we work from the perspective that all (types of) networks have spatiality. Thus, all, formal and informal, networks have a spatiality that may include local, regional, national and global aspects.

In line with a general celebration of regional economies and a new regionalism, the interest in networks during 1990s became strongly focused on regional networks, a situation characterised as "local fetishism" (Grabher, 2006). The cluster literature paid a great amount of attention to "space of flows" and the positive role of networks

[2] Multiple definitions exist for the terms spin-off and spin-out (for a discussion see Myint et al., 2005) and the definitional issues are further confused by the fact that the meaning of the two terms tends to be inverted in Europe and the USA. Therefore, we only use the term spin-off and apply a broad definition that covers a wide range of firm start-ups, including: (1) firms started as the result of a mother-organisation splitting off existing units or departments and the mother company holding (at least initially) equity stakes in the new firm and (2) firms formed by employees or groups of employees leaving an existing organisation to form an independent start-up firm. The parent entity can be a firm, a university or another organisation. In the second case the firm is only considered a spin-off if the employees received some form of assistance/support/stimulation from the parent organisation or if they are based on intellectual property/core capability developed during the employees' stay at the parent organisation.

in regional clustering processes. However, it was assumed that "the space of flows and the space of place showed a great deal of overlap" (Ter Wal and Boschma, 2008). The global aspects of networks tended to be ignored. Regions were treated as isolated islands of innovation.

Although remaining highly influential, these ideas became increasingly challenged by empirical studies that showed that firms in even the most developed clusters are often highly depended on non-local relations and networks for their knowledge. In fact, the non-local relations often play a crucial role in providing new (from the perspective of the region of cluster) knowledge. In the context of the biotechnology industry these ideas were supported by Owen-Smith and Powell (2004; 2006), Coenen, et al. (2006) and Moodysson and Jonsson (2007). Recent contributions to the knowledge-based theory of spatial clustering specifically incorporate the idea that firms in clusters are connected to both local and non-local networks and depend on local and non-local knowledge flows through 'local buzz' and 'global pipelines' (Bathelt *et al.*, 2004; Gertler and Wolfe, 2006). Clusters are understood as nodes of multiple and multi-scalar knowledge connections (Grabher, 2006).

This is not to say that the spatiality of the networks is irrelevant for the competitiveness of firms and regions. Firstly, from a neoclassical perspective one can point to the fact that proximity between actors in a network increases the efficiency of knowledge flow. Secondly, more important is the fact that the scale of some networks is strongly regional or national in character by nature. The membership of most regional/national professional organisations, chambers of commerce, industrial organisations etc, is nearly entirely regional/national. Many social networks, such as networks of former school-friends, are starting to include an increasing amount of globally dispersed members but retain a strong national character. In particular, many informal networks tend to have a strong regional/national character although some informal networks tend to have a significant international membership, e.g. epistemic communities.

Disagreement exists as to the salience or importance of the informal knowledge exchange both for the innovation capacity and competitiveness of firms and for regional clustering processes (Dahl et al. 2004). Some contributions argue that informal networks are important channels for knowledge exchange and that individuals in different firms and institutions informally provide each other with technical and market-related knowledge that can be of great value to the firm. Others are of the view that, although informal knowledge exchange does occur, the knowledge is generally of limited commercial or strategic value. Individuals will only exchange general knowledge that is of relatively low value to the firm, for example information about job openings. In addition, the knowledge may not flow freely throughout the local network but, instead, circulate in smaller (sub-) communities.

It is likely that the "quality" of the informal and formal networks and the type of knowledge that is exchanged differs from region to region. Although most regions have local networks, in some regions the networks will be bigger, and more conducive to knowledge flow, than in other regions. In addition, in some regions the networks will be better "exploited", leading to a greater amount of, and more strategic, knowledge flow (Saxenian, 1994). This is strongly influenced by regional institutional factors such as the local culture in relation networking and information

sharing, the quality of the institutions, and network policies (Dahl and Pederson, 2004)

It is therefore important to get an insight, into the "quality" of informal and formal networks, notably whether the structure is conducive for knowledge exchange, and into the type and quantity of knowledge that actually flows through the various networks. This insight is likely to provide lessons for network policy and the roles and contours of digital ecosystems in specific contexts, in this case a biotech digital ecosystem. Digital ecosystems are likely to play an important role in the creation of new and higher quality networks as well as the stimulation of knowledge flow through existing and new networks (enhanced exploitation of networks for knowledge flow and innovation)

3 RESEARCH METHODOLOGY AND DATA SOURCES

Task 11.6 set out to address three main research questions:

Q1. What are the structural characteristics of knowledge and innovation networks in the Irish biotechnology industry and are these conducive to knowledge flow?

Q3. Are the networks exploited for local knowledge flow?

Q2. What does this mean for the roles and the contours of a biotech digital ecosystem?

3.1 Methodology Research Question 1

The first research question was addressed through quantitative social network analysis. Social network analysis, one of the dominant traditions in network theory (Grabher 2006), is based on the assumption of the importance of relationships among interacting units or actors and that units don't act independently but influence each other. Relational ties between actors are viewed as channels for transfer or flow of resource. The social network approach provides a precise way to define important social concepts, a theoretical alternative to the assumption of independent social actors and a framework for testing theories about structured social relationships (Wasserman and Faust, 1994). As an analytical tool, social network analysis provides explicit formal statements and measures of social structural properties. These tools facilitate the conceptualisation of the interdependencies of behaviour and processes in networks. Structural properties are formally conceptualised in terms of nodes and linkages and captured in "sociograms".

Networks of relationships between social actors, be they individuals, organizations, or nations, have been used extensively over the last three decades as a means of representing social metrics such as status, power, and diffusion of innovation and knowledge (Watts, 1999; Kogut and Walker, 2001). Social network analysis has yielded measures both of individual significance, such as centrality (Freeman, 1979), and of network efficiency or optimal structure (Yamaguchi, 1994). Analysis of network structures becomes important when one is interested in how fragile or durable observed networks are. For example, what do network characteristics such as sparseness or clustering imply for the stability of the network structure?

The tradition of social network analysis has developed a range of conceptual devices, or frameworks, for analysing network structures that can facilitate an analysis of regional business ecosystems. A number of these were discussed in chapter 2. This research project focussed "small world" network analysis. Small world analysis is concerned with the density and reach of ties. A small world is a network in which many dense clusters of actors are linked by relationships that act as conduits of control and information (Milgram, 1967; White, 1970). In keeping with the age-old exclamation "it's a small world!", this type of network allows any two actors to be connected through a relatively small series of steps or links – despite the fact that the overall network may be quite sparse and actors may be embedded in distinct clusters.

As a result, actors in the network may in reality be "closer" to each other than initially perceived.

These small world networks, with high clustering and short global separation, have been shown by Watts (1999) to be a general feature of sparse, decentralized networks that are neither completely ordered nor completely random. Small world network analysis offers us a means by which we can gain insights into network structures and the role of these structures in facilitating (or hindering) the flow of innovation and knowledge throughout the entire network. Watts (1999) and Kogut and Walker (2001) advocate comparing an observed network with a randomised network (i.e. a random graph) that has the same number of actors (nodes) and same number of relationships (links) per actor as the observed. Simulations by Watts (1999) show that the structural stability of small worlds is retained even when a substantial number of relationships are replaced with randomly generated links. The network becomes more globally connected rapidly but the dense clusters are slow to dissolve. Thus, actors in the network can strategise and, rather than being disrupted, the small world structure is still replicated. In this way, networks that appear sparse can in fact contain a surprising degree of structure.

Small world analysis has been productively applied in the context of biotech clusters. Casper and Murray (2005) for example, reported important differences in the structure of the networks in the Cambridge and Munich biotech clusters. Small world analysis has important application in the context of regional biotech digital ecosystems. Knowledge will flow most efficiently in biotech ecosystems with small world characteristics. Where small world characteristics are absent, these can be created by adding a relatively small number of remote links to the network where the level of local clustering is already high (Grabher, 2006).

The formal description of small world networks presented here is as per Watts (1999), with the networks represented as connected graphs, consisting of undifferentiated vertices (actors) and unweighted, undirected edges (relationships). All graphs must satisfy sparseness conditions. The small world network analysis that follows in Section 6 is characterized in terms of two statistics:

- *Characteristics Path Length* (*L*): the average number of edges that must be traversed in the shortest path between any two pairs of vertices in the graph. L is a measure of the global structure of the graph, as determining the shortest path length between any two vertices requires information about the entire graph.

- *Clustering Coefficient* (*C*): if a vertex has k_v immediate neighbours, then this neighbourhood defines a subgraph in which at most $k_v(k_v -1)/2$ edges can exist (if the neighbourhood is fully connected). C_v is then the fraction of this maximum that is realised in *v*'s actual neighbourhood, and *C* is this fraction averaged over all vertices in the graph. In this way, *C* is a measure of the local graph structure.

In order to determine what is "small" and "large" in this analysis, Watts (1999) determines the following ranges over which *L* and *C* can vary:

1. The population size (*n*) is fixed.

2. The average degree k of vertices is also fixed such that the graph is sparse ($k<<n$) but sufficiently dense to have a wide range of possible structures ($k>>1$).

3. The graph must be *connected* in the sense that any vertex can be reached from any other vertex by traversing an infinite number of edges.

Fixing n and k enable valid comparisons to be made between many different graph structures. This also ensures that the minimum value for C is 0, while the maximum value for C is 1. The sparseness condition ensures that ensures that while the network is sufficiently well connected to allow for a rich structure, each element operates in a local environment which comprises of only a tiny fraction of the entire system. Finally, the requirement that the graph is connected guarantees that L is truly global statistic.[3]

The analysis focussed on three different networks in the Irish biotechnology, the formal network of researchers and related companies, the informal network of company directors and the formal network of spin-off companies.

Data collection started with an inventorisation of biotech companies in Ireland (see the next section on the Irish biotech industry for details). Following this, the team considered various sources of network data pertaining to these companies to feed the analysis, including the idea of gathering original data via a survey of all companies in the Irish biotech industry. This idea was abandoned because of resource issues and the low probability of obtaining a complete dataset. Eventually, two separate datasets were compiled for our social network analysis of the Irish biotech sector - a dataset on research networks structured by co-inventors and a set of micro-data on co-directorships and spin off links.

The first dataset has been compiled from patent data available from the Irish Patent Office (http://www.patentsoffice.ie/), US Patent and Trademark Office (http://www.uspto.gov/), and *Esp@cenet*, the European Patent Office (http://ep.espacenet.com/). The patent filings contain data pertaining to the publication date of the patent, the inventor(s), the applicant(s), a description outlining the purpose of the patent, records of patent citations, copies of the original documents submitted for the patent application, as well detailing the location of researcher (at a national level in the US and European Patent Office data, and at a regional level in the Irish patent office data).

The research team set about designing a template for data collection and constructing a dataset capable of capturing the key pieces of information provided by the patent filings. The final patent dataset comprised of the following categories: patent number, applicant(s), inventor(s), company of inventor(s) at time of patent publication, date of patent publication, location of inventor(s) at time of patent application.

By manual inspection of the patent filings of each Irish biotech company that has registered patents and population of the database template as outlined above, we established the researchers who worked on each patent, their employer at the time, and their location (whether they were foreign-based or located in Ireland). We take

[3] This coefficient (the CC) can be interpreted as an average probability of new connections for any given actor, given its degree

this formal research collaboration to represent a network conducive to knowledge flow between Irish biotech companies.

In order to compile the first dataset, a rigorous internet search of official company websites, media sources and the online *Fame* dataset[4] has been conducted. In this way, it can be ascertained whether a director of a given Irish biotech company also holds a directorship on another Irish biotech company. Joint directorships are then taken to represent a conduit of informal knowledge flow between the respective companies. This dataset also contains information on the founders of each company; serial entrepreneurs who form numerous companies; and spin-off companies. The database also identifies whether these spin-off companies emerged from existing private companies or universities. The date of establishment of all spin-offs and existing companies is also included in the dataset, allowing us to undertake an analysis of the evolution of the Irish biotech industry over time. We have endeavoured to verify the database through consultation with industry experts. All data were analysed with UCI-NET social network analysis software.

3.2 Methodology Research Question 2

The social network analysis provides insights into the structure of the networks and their ability to support knowledge flow. However, the structures are only suggestive of knowledge flow. The findings do not inform us about the extent and characteristics of the actual knowledge flow? It remains unclear how much knowledge flows through the links and how far the knowledge flows through the network (Dahl and Pederson, 2004). In addition, some knowledge is more strategic then other. It is therefore important to investigate what flows across the links (Grabher, 2006) – the extent to which the networks are exploited.

To answer this question interviews were conducted with members of the various networks. The most networked companies were identified on the basis of the findings of the social network analysis and 10 were selected for interview. The interviewees were shown the sociograms and invited to provide information regarding the knowledge flows (operating though the network) with directly and indirectly linked firms and institutions. The semi-structured questionnaire included questions regarding, amongst others: the type of knowledge (technical knowledge or know how/market knowledge), the strategic importance of the knowledge flow (rated on a 5-point Likert scale), the actual link, the process of the knowledge flow and the number of steps

In addition the interviews were used to obtain information about the extent of knowledge exchange between the companies with all other biotech companies (irrespective of whether or not these were identified in the sociograms as linked companies). For this the interviewees were show a list of all biotech companies in Ireland and asked to provide information regarding the knowledge flow. The questionnaire included questions regarding, amongst others: the location of the linked company; the way the companies are linked; The strategic importance of the

[4] The online *Fame* dataset provides ownership, governance and financial data on UK and Irish companies. <http://www.bvdinfor.com/Products/Company-Inforamtions/National/Fame.aspx.>

knowledge flow (rated on a 5-point Likert scale). The companies were asked to provide information about both inward and outward knowledge flow and both technological and know who/market knowledge flow. A copy of the questionnaire is included in the appendix. The interviews were typically conducted with one of the company directors. All interviews were recorded and transcribed.

3.3 Methodology Research Question 3

The findings regarding the structural characteristics of knowledge and innovation networks the Irish biotechnology industry and the extent to which these networks are currently exploited hold important lessons for network policy and the roles and contours of a biotech digital ecosystem.

Firstly, social network analysis can provide an important tool for identifying potential catalysts and early adopters in the initial deployment and development of the digital ecosystems. The concept of the digital business ecosystem would be most effectively diffused, and the use value of the various applications would be strongly augmented when the catalyst and early adopters have a central position in the Irish biotech networks.

But more importantly, detailed knowledge about the structure of knowledge and innovation networks will hold important lessons for the type of applications that will contribute most strongly to enhancing the knowledge flow in the sector. To distil these lessons, the above mentioned interviews with members of the biotech community included a number of questions on this topic. Five additional interviews were conducted with industry experts, including representatives from venture capital companies, industry associations and the indigenous enterprise development agency. In addition a focus group meeting was organised to discuss the research findings and solicit the ideas of the biotech community. This meeting was attended by 14 representatives of biotech companies, industrial promotion agencies, third-level colleges, venture capital companies, software companies, the OPAALS community and other industry experts.

Building on the research findings of the current Task 11.6, an additional OPAALS research exchange project focused on the development of one of the applications for the biotech DE, as suggested by the current research. The research exchange involved two OPAALS partners: NIRSA, NUI Maynooth and Fachhochschule Salzburg.

The overall aim was to exchange knowledge on the visualisation of social network analysis data. The anticipated output of the project included the visualisation of the various biotech networks using the EveSim network simulation tool, developed by Fachhochschule Salzburg, against the background of the Google Earth mapping application.

The exchange served three purposes:

1. Testing of the EveSim application in a new context, exploring possible extensions of its functionality. The NUIM experience with the EveSim network simulator in a new research context has provided valuable insights

into the functionality of the application. These insights will be reported in OPAALS Deliverable D10.20 (Emulation and testing of OPAALS P2P infrastructure by utilization of EveSim).

2. The visualisation of the different networks can play a role in the analysis of the spatial characteristics of the social networks in the Irish biotech industry. For example, the visualisation greatly facilitates the identification of the geography of spin off processes and information flows. These findings are reported in Section 5 of the current report.
3. Finally, the output functions as an example of a possible DE application.

The project required a number of different activities:

- Geo-coding of the actors in the various datasets in order to add a spatial dimension to the network data.
- Translating the data from Irish National Grid Projection to the specific format recognised by the EVESIM application. This involved a substantial amount of data preparation.
- Writing of programming syntax to facilitate the data being imported into the EVESIM software. The specific actions will be documented in D10.20 (Emulation and testing of OPAALS P2P infrastructure by utilization of EvESim)
- Adding additional functionality to the software to fully exploit the many facets of the Irish Biotech datasets. The specific actions will be documented in D10.20 (Emulation and testing of OPAALS P2P infrastructure by utilization of EvESim)

4 THE IRISH BIOTECHNOLOGY INDUSTRY

This section introduces the biotechnology sector in Ireland and presents the universe of firms that formed the starting point for the social network analysis

4.1 Modern Biotechnology

This study focuses on the modern biotechnology industry. The "modern" refers to the post-genetic engineering era - that is after scientists had developed the knowledge techniques and tools to intervene directly at the gene level (Laage-Hellman et al., 2004). The definition of the modern biotechnology and the operationalisation of such a definition are the subject of intense debate and controversy. A diversity of definitions exists. Some studies focus on particular industries while others argue that modern biotechnology should be regarded as a diverse set of knowledge bases and an enabling technology that has affected different industries (Brink, et al., 2004).

The OECD (2006) applies a combination of a single definition and a list based definition. Biotechnology is defined as the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or nonliving materials for the production of knowledge, goods and services'. It has been rightfully pointed out that this would encompass not only most biomedical R&D and commercial activity that involves laboratory animals or humans but also virtually all of agriculture, baking that uses yeasts, and the production of fermented beverages and foods, including beer and yogurt (Millar, H. 2007). In order to narrow the definition to modern biotechnology the OECD employs a list based definition that includes various techniques and activities: synthesis, manipulation or sequencing of DNA, RNA or protein; cell and tissue culture and engineering; vaccines and immune stimulants; embryo manipulation; fermentation; using plants for cleanup of toxic wastes; gene therapy; bioinformatics, including the construction of databases; and nanobiotechnology.

In terms of output or application, biotechnology tends to be coulour coded into red, white, green and blue biotechnology, although their does not appear to be a full agreement regarding the precise meaning of the colours. Red tends to be linked to medical biotechnology – used in the diagnosis and treatment of diseases. White biotechnology (sometimes referred to as grey biotechnology) focuses on using biological organisms to enhance industrial processes, often with an environmental nuance. Green tends to be linked to agricultural and food production biotechnology. Finally, blue is linked to aquaculture and marine biotechnologies.

Even if we agree over a definition of biotechnology we run into the difficulty of defining a biotechnology firm. When do we call a firm a biotechnology firm? Most firms use various technologies and produce various applications. Some firms produce or sell products that include a biotechnological agent but this agent is developed and manufactured by another company. Biotechnology is an "enabling technology". Many companies are enabled by biotechnology but the percentage to which they are enabled by biotechnology differs from company to company. As a way out, many studies limit the population to core or dedicated biotechnology firms. However we cannot assume that all activities and outputs of these firms are related to

biotechnology while the biotechnology activities of larger diversified firms can be substantial (Arundel, et al., 2007; Brink et al., 2004).

Partly due to the lack of official statistics and partly due to the ambiguous nature of the definition it is difficult to determine the size of the Irish biotechnology industry and its sub-sectors. Enterprise Ireland, provides a directory of biotechnology companies on its *Biotechnology Ireland* website. The directory lists hundreds of companies but includes many non-biotechnology companies, such as accountants and consultancy firms. The Circa Group Europe conducted one of the first attempts to inventorise the modern biotechnology industry InterTradeIreland (2003). The definition of modern biotechnology employed was "the application of molecular biology, cell and tissue culture or recombinant DNA techniques to organisms, cells or parts thereof in the manufacture of product or a as a component of service provision. Only companies whose staff skills/expertise or manufacturing processes were predominantly based on modern biotechnology were selected and surveyed. The report states that 41 companies in the Republic of Ireland responded to the survey but it is not clear what this means for overall size of the industry in Ireland. We do learn that in terms of number of companies pharmaceutical-biologics (12) and diagnostics (13) are the main sub-sectors, followed by agri-food (8), pharmaceutical services (6) and bio-environmental (2). 18 of the 41 respondents were foreign owned companies.

More recently the same consultancy group conducted a second survey (Irish Bioindustry Association, 2008). Here they used the above mentioned OECD definition. Only companies involved in R&D were included in the survey. Thirty-eight companies were identified according to this criteria but it is not clear from what sources this universe of firms was constructed. The results show that red biotech is by far the largest sub-sector in Ireland with 74% of the respondent firms classifying themselves as medical and a further 4 percent as medical and agricultural.

As part of the current research project and to develop a starting point for the social network analysis, the research team conducted its own inventorisation of the biotechnology industry. The "universe" of companies was based on the InterTradeIreland report and the Biotechnology Ireland web-site. All companies that matched the OECD definition and that were R&D-active in Ireland were included in this initial list, no matter what their size. The list was checked by industry experts which lead to the removal as well addition of companies. Based on information provided in previous reports, internet search and information obtained from industry experts, companies were categorised in five sub-groups - bio-pharma, bio-diagnostics, green biotech, white biotech and blue biotech. The sub-sectors were distinguished driven by the idea that they may have specific knowledge requirements and therefore be characterised by specific network structures, which may prove of interest to the research.

The resulting list of 80 biotechnology firms is presented in Table 4.1. This list is clearly larger than the lists included in the earlier surveys. The discrepancy is most likely related to the inclusion of all firms, including all start-up and early stage campus companies. The list includes 28 foreign-owned companies. Most of these companies are subsidiaries of large multinationals and have a strong manufacturing focus. The main indigenous sub sectors are bio-pharmaceuticals and bio-diagnostics. The bio-pharma sub-sector is even more dominant than the table suggests since the majority of the indigenous biotechnology services companies are active in

biopharmaceuticals. As regards company size the data are incomplete. But what we know is that all sub sectors are characterised by a strong involvement of SMEs. All but two of the indigenous companies are SMEs. It is estimated that the majority of indigenous companies in the list are micro-enterprises, employing less then 10 staff - often start-up companies or campus companies. The majority of the other indigenous companies are small enterprises, employing less than 50 staff. Most Irish SMEs in the bio-pharma sub sector are at a very early stage of their development.

Table 4.1 Research-active biotechnology companies in Ireland (case projects in brackets)

Dominant activity	*Indigenous companies*	*Foreign companies*	*Total*
Bio-pharma	17 (including cases 1 and 3)	16	33
Bio-diagnostics	16 (including a case not reported in this deliverable)	5	21
Green biotech	3	7	10
Biotechnology services	10 (including case 2)	-	10
White biotech, blue biotech and unknown	6	-	6
Total	52	28	80

Source: compiled on the basis of information obtained from InterTradeIrleand (2003), Biotechnology Ireland website and interviews with industry experts.

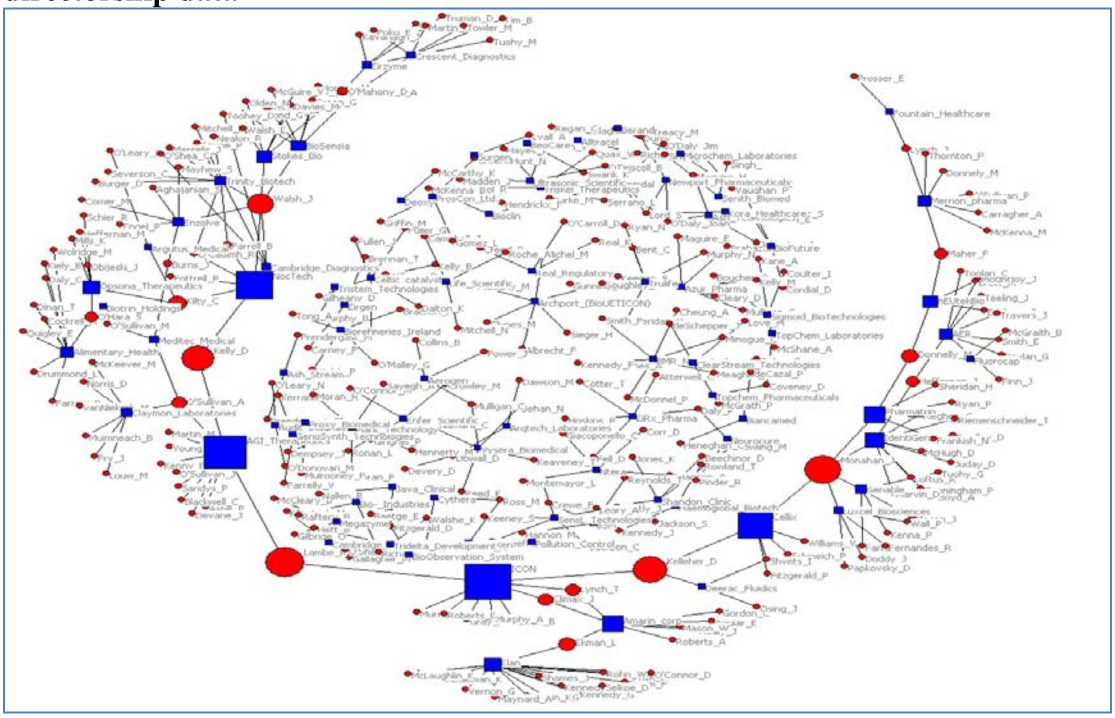
The list of 80 companies provided a starting point for the collection of data on networks of researchers, directors and spin-offs. This data collection process identified additional local companies. Although not always “core” modern biotech companies, where they were involved in related activities, a small number of such companies were added to the dataset.

5 STRUCTURAL PROPERTIES OF THE NETWORKS

Figure 5.1 presents a sociogram of the network connections in the Irish biotech industry, using data on directorships.[5] Some directors are director of more than one company, providing links or ties in the network which can support information flow and diffusion of the digital ecosystem concept. Figure 5.2 presents a sociogram of the network connections in the Irish biotech industry, but now using patent data. The network formed as biotech spin-off companies emerge from existing Irish biotech companies and universities is presented as a sociogram in Figure 5.3. On the face of it the sociograms would suggest that the networks have a low density.

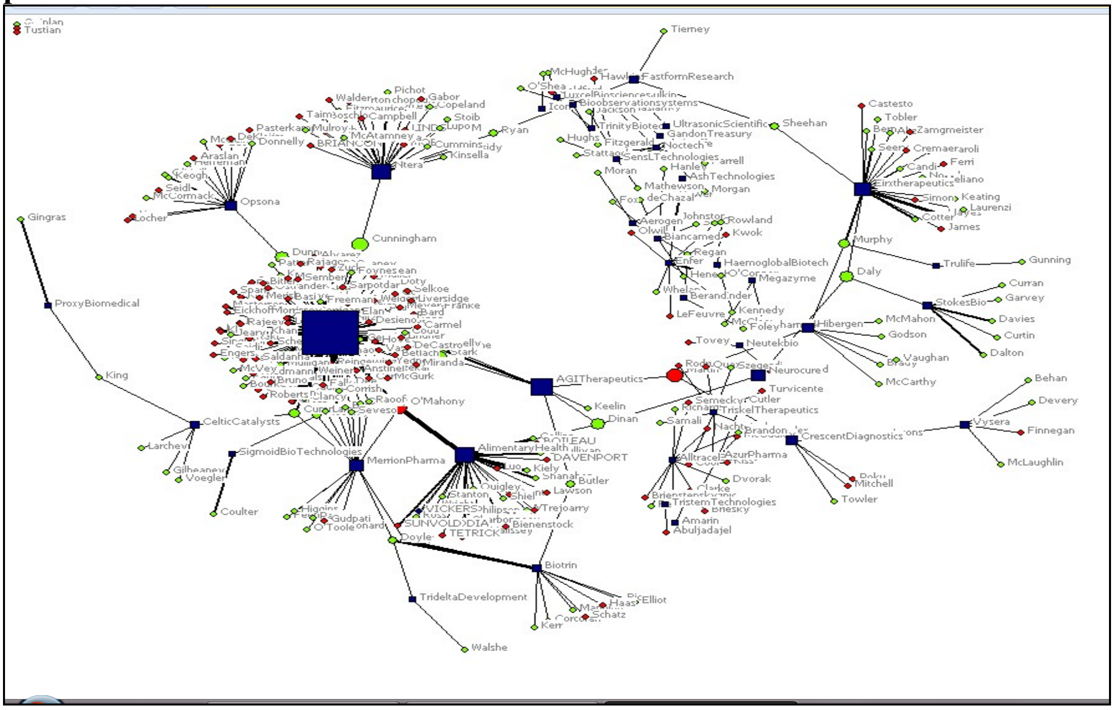
However as discussed in the methodology section, the structure of the networks may be such that despite low overall density, short path length and high clustering may still be features of the network. This would suggest that rather than being a sparse network unsuited for swift flows of knowledge, there may actually be potential for rapid diffusion of knowledge through the network if the right actors are targeted. Using both datasets, both informal knowledge flows and formal knowledge can be analysed and their resulting network characteristics compared. The results of the small world network analysis are now presented.

Figure 5.1: Network of Irish Biotech Directors and Companies, based on directorship data



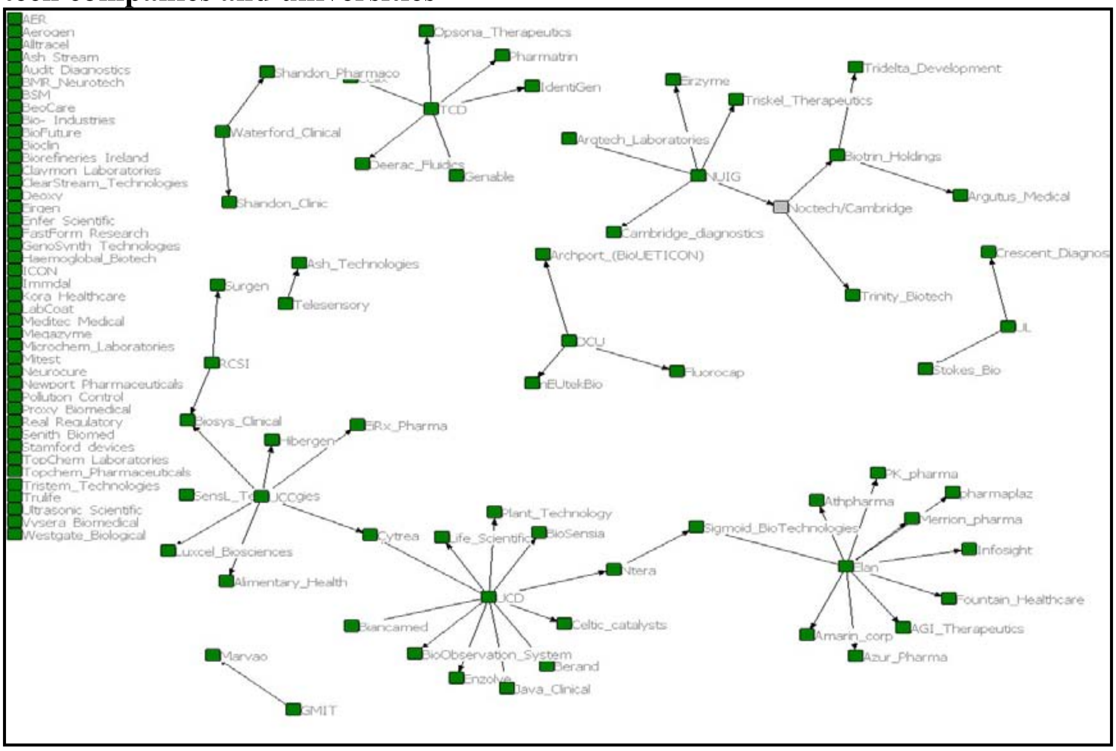
[5] Previous versions of this material were included in Van Egeraat and Curran (2010a and 2010b).

Figure 5.2: Network of Irish Biotech Researchers and Companies, based on patent data



Note: green indicates researchers based in Ireland: red indicates researcher based abroad.

Figure 5.3: Network of Irish Biotech Spin-offs emanating from existing Irish bio-tech companies and universities



Note: Nochtech/Cambridge is denoted in grey as it is no longer in operation.

Table 5.1 presents the results from the Irish biotech network of directors and companies, analysing the directors and companies separately (i.e. deconstructing a 2-node network into its constituent 1-node networks). While directors may be connected to each other by virtue of being on the board of the same company, this type of intra-company link is avoided by analysing the company-only 1-node network. Thus, presenting the results of both 1-node network analyses serves as a useful robustness check. In keeping with the formal description of small world networks presented in the methodology section, two central findings can be gleaned from Table 5.1. First, it is clear that both directors and companies are highly clustered (C = 0.948 and 0.669, respectively). This is particularly evident when compared to the low degree of clustering generated by a random network with the same number of nodes and ties as the highly structured observed networks (C = 0.039 and 0.062, respectively). Second, though the director and company networks are highly clustered, they are not characterised by long path lengths. This is in keeping with Watts' [16] findings that even as a network moves from a structured to a random graph, the path length decreases rapidly but the clustering is persistent. For the purposes of our Irish biotech study, this highly clustered/short path length characteristic of the directors network and the network of companies connected via directors has practical implications for the diffusion of informal knowledge and tacit knowledge throughout the entire network. It indicates that while knowledge is capable of travelling rapidly through the entire network, the challenge is get the knowledge to flow between the distinct clusters. It is exactly this challenge that a digital ecosystem can help overcome.

Table 5.1: Irish Biotech Industry Directors and Companies (via Directorships) Network Statistics

Variable	Directors	Companies
Density		
Density (for all directors/firms)	0.018	0.016
Total no. of ties	1,622	118
Average no. of ties (between those connected)	5.5	2.7
Clustering		
Cluster coefficient	0.948	0.669
Random Cluster coefficient	0.039	0.062
Path Length		
Average Path length among those connected	3.538	2.912
Random Average Path length	3.127	4.111

Note: No. of directors: 302; No. of firms: 86; no. of connected firms: 43

Table 5.2: Irish Biotech Industry Researcher and Companies (via patents) Network Statistics

Variable	Researchers	Companies
Density		
Density (for all researchers/firms)	0.163	0.041
Total no. of ties	16,110	64
Average no. of ties (between those connected)	52.5	2.78
Clustering		
Cluster coefficient	0.975	0.439
Random Cluster coefficient	0.570	0.099
Path Length		
Average Path length among those connected	2.091	2.256
Random Average Path Length	2.013	3.264

Note: *No. of researcher: 315; connected researchers: 307; No. of firms (that have registered patents): 40; connected firms: 23*

Table 5.3: A Comparison of Small World Network Statistics

	Path Length		Clustering		Actual-to-Random Ratio for:	
Network	Actual	Random	Actual	Random	Length	Clustering
Irish Biotech Directors	3.538	3.127	0.948	0.039	1.131	24.31
Irish Biotech Companies (via directors)	2.912	4.111	0.669	0.062	0.708	10.79
Irish Biotech Researchers	2.091	2.013	0.975	0.570	1.039	1.711
Irish Biotech Companies (via patents)	2.256	3.264	0.439	0.099	0.691	4.434
German Firms[1]	5.64	3.01	.84	.022	1.87	38.18
German Owners[1]	6.09	5.16	.83	.008	1.18	118.57
Film Actors network[2]	3.65	2.99	.79	.001	1.22	2,925.93
Power Grid network[2]	18.70	12.40	.08	.005	1.51	16.00
C. *Elegans* network[2]	2.65	2.25	.28	.05	1.18	5.60

[1] Kogut and Walker, 2001; [2] Watts and Strogatz, 1998

Comparable results emanating from the network of Irish biotech researchers and the network of Irish biotech companies via patents are presented in Table 5.2. While the findings outlined above can be interpreted as capturing informal knowledge flows, the results of Table 5.2 are based on patent data and therefore refer to formal knowledge flows. Once again, the salient findings are those of high clustering and short path lengths for both the researcher and company networks. However, in this instance the company network is noticeably less clustered via patents than it was through directors. This suggests that formal knowledge flows through the network in a different, slower, manner than informal knowledge. This may also have important practical implications both for understanding the process of knowledge diffusion in the Irish biotech industry and for ensuring optimal design and operation of a digital ecosystem in such a setting.

We now consider our additional formal network, which comprises of Irish biotech spin-off companies emanating from both existing Irish biotech companies and universities. The sociogram presented in Figure 5.3 illustrates that the formal network of spin-off companies and their company or university “spinners” exhibits low density, as the number of “spinner” nodes (15) is only a tiny fraction of the total number of nodes (105) in the entire sociogram. Furthermore, a low level of clustering is apparent in the spin-off network as the observed spin-off companies, whether they emanate from existing companies or universities, do not appear to have borne further waves of new spin-off companies. A further interesting feature captured in Figure 5.3 relates to the origins of Irish biotech spin-offs: the observed spin-off companies have emerged to a much greater extent from universities than from existing companies. The implications of this university-orientated spin-off process will be discussed in detail in Section 6.

The key features of the spin-off sociogram (Figure 5.3) highlighted above are suggestive of the absence of small world characteristics in the spin-off network. Once again, we undertake the statistical small world network analysis in order to investigate this further. The results, presented in Table 5.3) confirm this absence of small world properties. The density measure (0.005) and the clustering coefficient of zero are testament to the sparse nature of the spin-off network and the absence of any notable pockets or sub-groups of companies within this network. While the Biotech research network via patents discussed above exhibited small world characteristics but to a lesser extent than the informal co-directorship network, the formal network of spin-offs does exhibits no small world characteristics.

Finally, Table 5.4 presents a comparison of small world networks identified in a range of existing studies and allows us to assess “how small” the networks in the Irish biotech industry are. The small world network statistics of the Irish biotech industry are compared with comparable statistics from a study of networks of German firm owners [17] and a study that reported on three types of networks [25]: a network of film actors connected by participation in films; a power grid network representing links between generators, transformers, and substations in the western United States; and C. Elgans, which is the completely mapped neural network of a worm. Comparison across the networks illustrates once again the strong small world characteristics of the director network and the network of companies connected via directors, as well as the lesser degree of clustering in the small world network of Irish biotech researchers and the network of Irish biotech companies via patents.

Table 5.4: Irish Biotech Industry Spin-off Network Statistics

Variable	**Spin-offs**
Density	
Density (for all nodes)	0.005
Total no. of ties	112
Average no. of ties (between those connected)	1.067
Clustering	
Cluster coefficient	0.000
Random Cluster coefficient	0.023
Path Length	
Average Path length among those connected	1.145
Random Average Path Length	1.067

Note: No. of nodes: 105; connected nodes: 63;

The network data can be used to explore the spatial characteristics of the biotechnology networks. The formal network of investigators (patents) has both local and non-local aspects. In Figure 5.2, the green nodes denote investigators located in Ireland and the green nodes denote investigators located in other countries. Many companies owned patents that involved only Irish-based investigators. At the same time, the majority of companies owned at least one patent that was linked to foreign-based investigators, although only 10 companies and 4 universities owned at least one patent that was linked to both local and foreign-based investigators. These formal network data support the view that although the investigator network has a strong local component, the Dublin region, and even Ireland as a whole, should not be treated as "an isolated island of innovation"

The informal network of company directors is far less global in character. Only a small number of Irish companies have a non-Irish director on their board, although quite a number of Irish directors hold a directorship of a company based abroad. This result should however not be generalised to other informal networks in the biotech industry. It is true that the membership of most national professional and industrial organisations is nearly entirely national. However, the interviews demonstrate that other informal networks such as the professional networks of individuals, the epistemic community and network of university alumni include a large international component.

Although a large part of the Irish biotech industry is concentrated in the greater Dublin Area (Van Egeraat et al. 2009), the directorship network is not bounded by the city-regional scale. Many directors of companies in Dublin have links with companies outside the city-region. The network visualisation exercise (see chapter 8) identified a total of 25 cross-regional directorship links, notably between companies in Dublin, Cork, Galway and Limerick and Athlone. Therefore, from a directorship network

perspective, the relevant scale of the biotech ecosystem is national, rather than city-regional.

In relation to the spin-off network, Figure 5.3 shows that the majority of spin-offs in the Irish biotech industry have been spun from one of the Irish universities, with UCD and TCD accounting for the lion's share. The diagram identifies two series of firm-firm spin-offs – one starting at Elan, giving rise to a number of bio-pharmaceutical companies and one starting at Noctech (itself a university spin off), leading to a group of bio-diagnostics firms. The geography of the spin-off processes is surprising. Existing theory and empirical accounts generally suggest that spin-off firms locate in the same region as the spinner firm, representing an important mechanism for localised industrial agglomeration and clustering. The visualisation of the Irish biotech spin-off network (see chapter 8) presents a partially different picture. Although many of the spin-offs of Dublin-based institutions/firms established themselves in Dublin, a relatively large number of firms that were spun off from institutions/firms located outside Dublin, ended up in different regions, notably in Dublin. Of the 22 spin-offs that originated in institutions/firms outside Dublin, 13 ended up in a different region and 11 in Dublin. Therefore, although a large part of the industry is concentrated in Dublin, we would argue that, from a spin-off network perspective, the relevant scale of the biotech ecosystem is again national rather than city-regional..

6 ACTUAL KNOWLEDGE FLOWS

The social network analysis provides insights into the structure of the networks and their ability to support knowledge flow. However, the structures are only suggestive of knowledge flow. The findings do not inform us about the extent and characteristics of the actual knowledge flow. It remains unclear how much knowledge flows through the links and how far the knowledge actually flows through the network (Dahl and Pederson, 2004). In addition, certain knowledge or information may be of greater strategic importance than other knowledge. It is therefore important to investigate what actually flows across the links (Grabher, 2006) – the extent to which the networks are exploited.

To answer this question interviews were conducted with members of the various networks. The most networked companies were identified on the basis of the findings of the social network analysis. Ten were selected for interview and eight of these cooperated. The interviewees were shown the sociograms and invited to provide information regarding the knowledge flows (operating though the network) with directly and indirectly linked firms and institutions. The semi-structured questionnaire contained questions regarding, amongst others: the type of knowledge (technical knowledge or know how/market knowledge), the strategic importance of the knowledge flow (rated on a 5-point Likert scale), the actual link and the process of the knowledge flow.

The interviews show that the three particular networks under consideration are poorly exploited, although to different extents. With respect to the network of investigators (patents) we found no evidence of companies obtaining knowledge from either the directly or indirectly linked companies (resulting from this particular network). Part of the reason for this surprising result lies in the fact that many of the links in the sociograms are related to 'old' collaborations. These collaborations are no longer active and the inventors involved have since moved to other companies. In effect, the formal co-investigator links have become informal links, part of the personal professional networks, linking other companies.

The network of directors involves a greater amount of knowledge flow. Interestingly, apart from one case, the flows do generally not involve technical knowledge concerning the directly linked firms. In fact three interviewees pointed out that they had signed confidentiality agreement which prevented them from divulging strategic information about their company to other companies.

Most interviewees stated that their firms had received valuable general business and know-who type knowledge from their directors, including from those with multiple directorships. However, all but one of the interviewees argued that the link with the directorship network was of limited relevance. The knowledge generally involves the embodied knowledge of the director. It is difficult to assess the role of the directorship network for the accumulation of this embodied knowledge inherent in the director. What is clear though is that, for the focal firms themselves, the directorship network plays a relatively limited role in the identification of, and/or introduction to, relevant actors in the Irish market. As will be discussed below, the interviews show

that the directorship network is merely one, and a relatively less important, network in a broader set of informal network relations connecting companies. Interviewees typically pointed out that they personally knew and could contact a large part of the Irish biotech scene on the basis of these other networks.

Directors of venture capital companies form a special case. Many boards of directors of biotech companies include directors of the investing venture capital companies. In operating their venture capital business, these directors have met most of the Irish biotech companies. "I know almost every name on this sociogram. I have their phone numbers and I can call them if I want to. We see all these people. Everybody who has looked for money has come through our doors." (Director, venture capital company) These directors are therefore a potentially important source of know-who and business related knowledge. However, this knowledge is not based on his directorship links. It is the embodied knowledge of the specific director obtained during his activities at the venture capital company.

Interestingly, most interviewees acknowledged that directorship networks do play a more important role at the international scale. A number of the interviewed companies have corporate interlocks with firms outside of Ireland and these are frequently used to obtain information about firms or markets abroad. "If this was a European analysis or a global one, then it would be much more likely that I would be skipping through directors ... Because it is not my local area, I would rely far more heavily on those fellow directors in the US to point me in the right direction." (Interview biotech firm).

The interviews provided evidence of more substantial knowledge exchange in the third network, the network of spin-offs. Two of the three more formal spin-offs in the sample involved both technical and know who / market type knowledge and in both cases some of the knowledge was considered relatively important for the innovative performance of the firm. In one case the spin off firm and the spinner firm started a joint product development project which involved a substantial amount of knowledge exchange, both technical and market type knowledge. Interestingly, the potential for the project was identified by a staff member of the spinner firm who served as a member of the board of the spin off firm. This person "has been the bridge. ... He has an understanding of both sides and is therefore in a good position to advise." The other case involved a formal university spin off. This was characterised by an ongoing flow of technical knowledge between the spin off firm and the university department, mainly facilitated by one of the company founders who had retained his position as university professor.

The less formal spin-off relations in the sample tend to involve lower levels of knowledge flow, and the flow tends to be limited to know-who and market related knowledge of limited strategic importance. In most cases it is arbitrary whether or not the knowledge flow should be considered as a function of the fact that we are dealing with a spin-off company. Instead, it may be more appropriate to interpret it as facilitated by the personal professional network of people which are partly based on employment history (see below).

Apart from the firms linked by the three networks, the interviewed companies did obtain knowledge from other local firms. To investigate the extent and character of the overall knowledge flow, companies were asked to provide information about the

companies or institutions they had turned to for either technological advice or business/know-who type knowledge during the last five years. For this the interviewees were shown a list of all biotech companies/institutions in Ireland and asked to provide information regarding the knowledge flow. The questionnaire included questions regarding, amongst others: the location of the linked company; the way the companies are linked; the strategic importance of the knowledge flow (rated on a 5-point Likert scale).

With respect to technical advice all interviewed companies had been in contact with between 3 and 9 other Irish companies/institutions. Universities were the main sources for technical knowledge, accounting for 58% of the links. All interviewed companies had technology- related contact with several Irish universities and all universities were mentioned by at least two respondents. However, in general, the majority of cases involved very limited technical advice or knowledge flow. These links involved relatively standard service provision such as analytical services, clinical trial work by CROs etc. It is debatable whether this can be considered knowledge flow. Interviewees themselves expressed unease with linking some of these contacts with knowledge flow. In addition, in most cases the strategic importance is limited. The average score for the strategic importance of the cases was 2.5 on 5-point Likert scale. Most strategic links tend to involve universities.

Although some of these contacts started with a “cold call”, we found evidence of informal networks facilitating the identification of the relevant actors. However, the number of instances of companies intentionally consulting other local companies for local know-who/business type knowledge, was relatively small. Interviewees typically mentioned one or two such links although one company declared 14. The relatively low level of intentional local know-who exchange is due to the fact that companies are relatively well informed about the local actors. This is not to say that networks play no role. The level of personally embedded know-who type knowledge is, in fact, largely a result of long term participation in local networks. In addition, the informal networks are strongly exploited for obtaining knowledge about actors in other countries.

A combination of, mainly informal, personal networks are at play, including professional networks of the individuals, student networks and social networks. Most important are the personal professional networks, built up over years, linking former and current colleagues and commercial contacts. “The most important channel is related to people moving on” (Interview biotech company). During their careers individual actors come into contact with a large section of the Irish biotech industry. Although some of the relations are closer than others, most facilitate contact and information flow over a long period. As one interviewee put it: “We were collaborating with [this company] on some of their technology. That is ten years ago. But it is still easier to pick up the phone, asking for somebody by name, if you have met the person” (interview biotech company).

Another important network is formed by university alumni. “UCD is part of the extended diaspora from my TCD days. So, colleagues from TCD who are now based at UCD. We retain a fairly open channel with them and indeed other post-docs” (Interview biotech company).

Apart from the personal networks, an increasingly important set of networks is created by the various industrial or research support agencies, including IDA, Enterprise Ireland, university tech transfer offices, Science Foundation Ireland etc. These institutions are increasingly active in trying to match research output with commercial partners and are a potential source of knowledge, notably intellectual property. Interviews indicated that, although until now not many deals had developed via this route, these networks are expected to become increasingly important.

The findings regarding the level of exploitation of the three networks contain some surprising elements, at least at first glance. The formal network of spin-offs turns out to be the most intensely exploited, notably for technical knowledge flow. This is the network that was considered least conducive to knowledge flow on the basis of social network analysis. The explanation for this apparent contradiction is that the knowledge flow tends to be contained between the spinner and the spin-off firm. That is, the level of diffusion to the broader industry is limited.

On the other hand, the network that was suggested to be most conducive to knowledge flow according to the social network analysis exercise, the informal network of company directors, appears to be strongly under-exploited - both for technical and know-who type knowledge flow. Two points need to be made here: First, the directorship network should not be interpreted as a separate network, functioning independently of all other networks. Rather it is part of a large integrated set of partly overlapping informal networks linking the Irish biotechnology firms. It is clear, though, that the directorship network is a relatively unimportant element in the overall informal network constellation. Other informal networks, notably the professional networks of the individuals and network of university alumni involve far more links and therefore play a far greater role in knowledge flow.

Secondly, the fact that most (established) biotech companies make a lower than expected use of the informal networks for the active or intentional search for know-who type knowledge concerning the local industry does not mean that these networks are not exploited or not valuable. The Irish biotech industry is small and it is precisely due to the long-term participation in the local informal networks that most established actors are, and remain, (passively) informed about the relevant players in the local industry. In addition, the interviews do suggest that less established firms do rely more strongly on their informal networks for know-who type knowledge and introductions to local actors. Finally, the informal networks do play a significant role in (intentionally) obtaining know-who type knowledge about non-local actors.

7 IMPLICATIONS FOR A BIOTECH DIGITAL ECOSYSTEM

The insights into the structural characteristics of the knowledge and innovation networks, and the actual level of knowledge flow, of the Irish biotechnology sector yield important lessons regarding the roles and contours of a biotech DE. First, social network analysis can serve as an important tool for identifying potential catalysts and early adopters in the initial deployment and development of digital ecosystems. The concept of the digital business ecosystem would be most efficiently diffused, and the use value of the various applications would be strongly augmented, when the catalyst and early adopters have a central position in the Irish biotech networks. But, more importantly, a detailed understanding of the structure of knowledge and innovation networks provides important lessons regarding the type of applications that would make the greatest contribution to enhancing the knowledge flow in the sector.

To distil these lessons, interviews were conducted with members of the biotech community, industry experts, including representatives from venture capital companies, industry associations and the indigenous enterprise development agency. In addition, a focus group meeting was organised to discuss the research findings and to solicit the ideas of the biotech community. This meeting was attended by 14 representatives of biotech companies, industrial promotion agencies, third-level colleges, venture capital companies, software companies, the OPAALS community and other industry experts.

This section begins with a summary of the relevant findings of related research conducted in the context of OPAALS phase II, notably Task 11.1 (Van Egeraat *et al.*, 2009). These findings were the starting point for the current study and provide an important context for the subsequent discussion of the implications of the findings of social network analysis. Finally, we report on the ideas emanating from the interviews and discussions with the members of the focus groups.

A Digital Ecosystem (DE) is a self-organising digital infrastructure aimed at creating a digital environment for networked organizations that supports co-operation, knowledge sharing, the development of open and adaptive technologies and evolutionary business models (Nachira et al., 2007). A DE provides structures of communication and collaboration that can facilitate collective learning, knowledge flow and innovation across SMEs and other actors.

Task 11.1 of OPAALS phase II involved case studies of innovation projects in the Irish biotechnology industry. These case studies took the form of “innovation biographies”, tracing the history/genealogy of particular innovation projects. Based on the finding that the innovation projects of companies in the Dublin area involve very little collaboration with other regional or even national actors, the study concluded that an Irish biotech DE is unlikely to play a significant role in promoting regional development if it was designed to facilitate knowledge flow between regional actors who are collaborating in a specific innovation project (i.e. a project management tool). A DE can, of course, play an important role in facilitating sporadic examples of innovation projects that involve local collaboration. But in the short to

medium term this is unlikely to have a significant impact on overall regional development and the competitiveness of the sector in the region.

In the Irish context, a DE is more likely to stimulate regional development by acting as a more general communication tool and knowledge resource, connecting all regional players in the biotechnology industry (irrespective of whether or not these actors are partners in a specific innovation project). The fact that Irish biotech companies rely largely on global sources of knowledge for individual innovation projects does not mean that the DE has a limited role here. The DE could act as an important regional *resource of knowledge*. It could, inter alia, allow firms and individuals in the region to exchange knowledge; allow individual actors to advertise their services; provide information about initiatives of industrial promotion agencies; allow individual actors to communicate recent developments in a specific field; provide a brokerage facility for local venture capital and other sources of finance; provide employment services; provide a vehicle for regional-level associations to advertise their services and connect regional actors to various knowledge resources.

The regional development agencies and industry associations have already developed biotech industry specific web-sites that aim to act as a knowledge resource. The DE that was envisaged in Deliverable 11.2 had a greater and rather different functionality. First of all, the underlying philosophy of peer-to-peer interaction and democracy would allow all regional actors to provide content. The active involvement of the regional actors is, in itself, likely to increase the intensity of the knowledge flow in the DE.

Rather than simply providing data on companies and actors, primarily aimed at generating collaborative innovation projects, the DE adds a strong assistance/support functionality. Companies and individual actors provide information about their knowledge assets and requirements. One of the central questions becomes *"what knowledge that could be of value to me do you have, and are you willing to share?"* This may be particularly beneficial to young companies and new actors, but not exclusively so.

The DE was envisaged to provide a multi-level data/communication structure. Some levels are shared by all firms and individual actors while others are only accessible to smaller groups. The different levels mediate knowledge and information with different levels of sensitivity, requiring different levels of social proximity and trust.

The DE should involve the entire social world of the firms linked to the specific inter-firm networks to which firms belong, as well as to the loose web of ties that people within innovation projects share with others in the industry. Rather than merely facilitating knowledge flow and collaboration related to a specific innovation project, a DE becomes a new type of public space, facilitating 'interpretive action' (Lester and Piore, 2006). This new public space facilitates both intentional knowledge flow and "buzz". A well functioning DE has the potential to intensify the level of local buzz. This will, of course, not happen in the absence of a certain level of social proximity and trust. The DE is not a substitute for face-to-face context but offers an additional (virtual) local space to intensify the level of local buzz.

Given the important knowledge generating role of the universities, one of the most valuable roles of a biotech DE is to facilitate knowledge transfer from these

universities and research institutions. Universities and their lead scientist would therefore be the most important players and potential catalysts in a DE organised on a regional basis. Clinicians, with their crucial knowledge about unmet market needs, were also accorded an important role. The digital ecosystem will mainly connect small and medium scale enterprises. The importance of formal education suggests that epistemic communities should be an important element in the structuring of a biotech DE. With venture capital being an essential element of the biotech eco-system, a DE may play an important venture capital brokerage role. Finally, industrial development agencies are important both as a source of funding and know-who knowledge.

Based on the results of the social network analysis and qualitative investigation of the exploitation of the networks we can confirm most of these points, as well as adding a number of further ideas:

- The results confirm that, rather than focussing on individual formal networks, the biotech DE should involve the entire social worlds of firms - the entire constellation of informal social networks, including professional networks of individuals, university alumni, and social networks.
- A biotech DE can play a valuable role in facilitating the flow of know-who and business/market type knowledge related to Ireland, particularly benefitting new, less established, firms. It will be of limited benefit to established firms. This can involve the exploitation of existing informal network links and the stimulation of new network links.
- A biotech DE can play a particularly valuable role in stimulating the flow of know-how and business/market type knowledge related to foreign locations. This can also involve the exploitation of existing informal network links and the stimulation of new network links.
- Existing informal networks in the biotech industry involve limited technical knowledge flow and diffusion, mainly due to efforts to protect firm-specific knowledge and intellectual property. There is however scope to better exploit the informal network for the flow of non-sensitive technological knowledge.
- The central importance of universities as the principal source of technical knowledge suggests that a biotech DE should specifically aim to facilitate the development and exploitation of formal and informal networks involving these universities.
- The analysis of the various networks suggests that the Irish biotech ecosystem functions at a national scale. Although many firms are spatially concentrated in the Dublin area, the firm are part of a national ecosystem. A biotech DE in Ireland should therefore be structured on a national, rather than a regional scale

The relevance of these ideas regarding the structure and possible functions of a Biotech DE was discussed and validated during interviews with key industry players and during a workshop on the development of a DE for the Biotechnology industry in the Greater Dublin Region, attended by key industry players and industry experts (Van Egeraat and Curran, 2009). Below we identify the main messages arising from the workshop and these interviews.

- The workshop delegates agreed that in the Irish biotechnology industry a DE is unlikely to play a significant role in promoting regional development when it is applied mainly as a project management tool, i.e. for facilitating efficient, secure and democratic communication and knowledge flow between regional actors who are collaborating in a specific innovation project. However, delegates identified a number of specific examples of projects for which the DE could play such a role and this type of application should therefore be offered as part of a wider DE. Examples of such projects include the Centres for Science, Engineering and Technology (CSETs). CSETs, funded by the Science Foundation Ireland, aim to link scientists and engineers in partnerships across academia and industry to address crucial research questions, foster the development of new and existing Irish-based technology companies, attract industry, and expand educational and career opportunities in Ireland in science and engineering. These cooperative projects would benefit from project management applications run on the DE architecture.
- The delegates agreed that in the Irish context, a DE is most likely to stimulate regional development by acting as a more general communication tool and knowledge resource, connecting all regional actors in the biotechnology industry (irrespective of whether or not these actors are partners in a specific innovation project).
- The delegates agreed that universities and other research institutions will be crucial actors of a Biotech DE.
- SMEs in the biotech industry are believed to be particularly interested in knowledge about, amongst other thing,
  - collaborators
  - common providers of technical and product development expertise
  - members willing to join the scientific advisory board
  - funding and finance
  - qualified and skilled staff
  - Intellectual property
- In the light of the limited use of the Biotechnology-dedicated website run by Enterprise Ireland, the national industrial promotion agency, delegates argued that a biotech DE will need to differentiate itself on the grounds of its interactive character and the notions of *sharing* and *reciprocity*.
- The delegates agreed that a regional DE could play an important role in the sharing of knowledge about the location of foreign actors and providing introductions. Hence one obvious application would be a forum where regional actors can consult each other on a reciprocal basis about the location of actors and sources of knowledge.
- In addition, workshop delegates and some of the interviewees agreed that there was scope in the concept of a regionally-based science forum. Here biotechnology scientists and technicians in companies and universities could ask for advice about, and interactively discuss, scientific and technical problems.
- Two interviewees pointed to the free-rider problem and the potential problem of receiving too many requests for information. The first problem could be

addressed by making the use of the forum conditional on an actor's availability to be contacted. One way to address the second problem would be to attach a fee to the use of the forum.

- Workshop delegates pointed to the fact that many SMEs in the biotech sector are experiencing difficulty in attracting suitably skilled and qualified staff. In this context, an electronic interactive labour exchange, matching skilled people to jobs, could prove a popular and beneficial application.
- Some of the workshop delegates suggested the idea of an electronic venture capital (VC) brokerage tool. However, one interviewed VC firm did not concur with the idea of a brokerage tool. The local market was deemed too small. Local companies are sufficiently informed about the local VC market. On the other hand, one of the interviewees was of the opinion that many local biotech firms have limited knowledge about VC possibilities in other markets such as the US. This could therefore be an important topic for the earlier mentioned regional forum.
- One workshop delegate suggested the idea of an intellectual property (IP) exchange. This idea was strongly supported by one of the interviewees. Although, the size of the Irish market for IP is relatively small, the amount of IP being developed is substantial and increasing. A large number of universities and companies are active in the development and various agencies are involved in linking this IP to potential customers. The interviewee perceived a need for a single port of entry for the sharing of information regarding available IP, simplifying the search for "commercialisable" product technologies and experts in universities. However, another interviewee argued that general information about the availability of IP is of limited value. In principle such a facility is already available in the form of an EU network for technology licensing opportunities. The challenge lies in identifying the relevance of IP to specific companies. Enterprise Ireland attempts to address this challenge by employing a specialist with the task of inventorising technology outputs on a global scale, notably in the USA. However, according to the interviewee, this is still not focussed enough – more a vague prospectus exercise. Due to its interactive character, a biotech DE may lead to more relevant knowledge flow.
- The DE can be used to provide a directory tool, containing information about and promoting regional actors, and to promote Ireland as a biotech region. As such, it would have a role similar to the web-site run by Enterprise Ireland, the National enterprise development and promotion agency

Based on the results of the network analysis, the interviews and the focus group meeting, we believe that the following applications have the greatest potential to kick-start a biotech DE in Ireland:

- A forum for regional actors (in universities; research institutions and private enterprise) to consult each other on a reciprocal basis about the location of (regional and extra-regional) actors, sources of knowledge and relevant intellectual property. This forum would involve a network visualisation tool which identifies national and international connections of actors. This idea is illustrated in the next section.

- A regionally-based science forum for biotechnology scientists and technicians. Here biotechnology scientists and technicians in companies and universities could ask for advice about, and interactively discuss, scientific and technical problems.
- A biotechnology sector-dedicated electronic interactive labour exchange, matching skilled people to jobs.
- A directory tool, providing information about and promoting regional actors, as well as promoting Ireland as a biotech region.

8 NETWORK VISUALISATION

This section presents the biotech network visualisation tool developed by a cross-institutional team in the context of an OPAALS research exchange project. The research exchange involved two OPAALS partners: NIRSA, NUI Maynooth and FH Salzburg.

The overall aim was to exchange knowledge on the visualisation of social network analysis data. The anticipated output of the project included the visualisation of the various biotech networks using the EveSim network simulation tool, developed by Fachhochschule Salzburg, against the background of the Google Earth mapping application

.

This exchange served three purposes:

1. Testing of the EveSim application in a new context, and exploring possible extensions of its functionality. The NUIM experience with the EveSim network simulator in a new research context has provided valuable insights into the usability of the application. These insights will be reported in OPAALS Deliverable D10.20 (Emulation and testing of OPAALS P2P infrastructure by utilization of EveSim).
2. The visualisation of the different networks can play a role in the analysis of the spatial characteristics of the social networks in the Irish biotech industry. For example, the visualisation greatly facilitates the identification of the geography of spin-off processes and information flows. These findings are reported in section 5 of the current report.
3. Finally, the output functions as an example of a possible DE application. We will expand on this idea below.

The visualisation depicts the various networks in the Irish biotech industry against the background of Google Earth mapping application. The output presents the actors of the networks, their location and their connections in a very flexible way. Clicking on a firm's icon provides additional data about the particular firm. Clicking on the link provides information about the individual represents the link between two firms. Figures 8.1 and 8.2 provide screenshots of the possible output.

Such a facility, with expanded functionality, could be an important component of a biotech DE. In section 7 we suggested the development of a forum for regional actors (in universities; research institutions and private enterprise) to consult each other on a reciprocal basis about the location of (regional and extra-regional) actors, sources of knowledge and relevant intellectual property. The visualisation tool could play an important role in identifying connections of potential partners in Ireland and abroad. This could allow actors to identify common contacts who may provide helpful introductions. On an Irish scale, such a facility would benefit mainly new, less established, firms but on an international scale this would benefit all firms. In order for this opportunity to be exploited, additional functionality would need to be

developed. Notably, the tool would have to be integrated in a DE so that firms could independently operate the visualisation tool.

At the moment the tool only integrates publicly available data on a limited number of networks. As discussed, this data represents only a small proportion of a large number of informal networks that individuals and firms are connected to. The utility of the tool would be greatly enhanced if these other networks were captured as well. However, there is currently no data on these networks. They could be obtained by allowing actors to upload their own information about network connectivity. This would, of course, involve a significant amount of further development.

Figure 8.1: Screenshot visualisation network of spin-offs

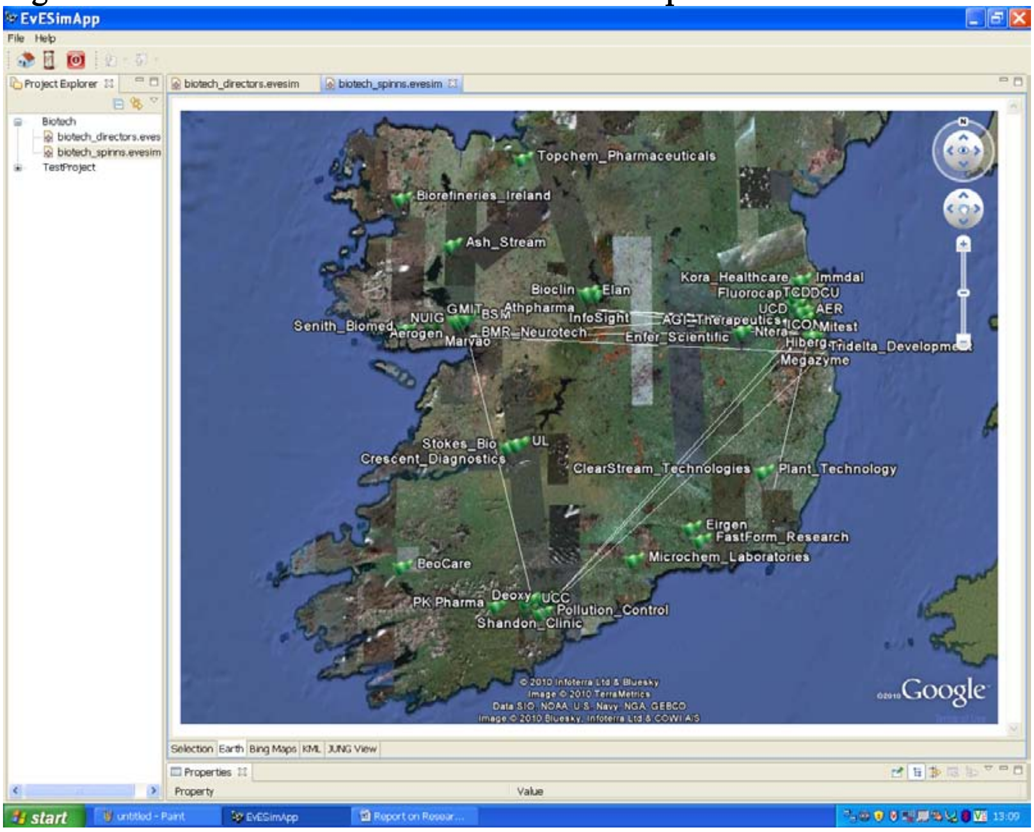
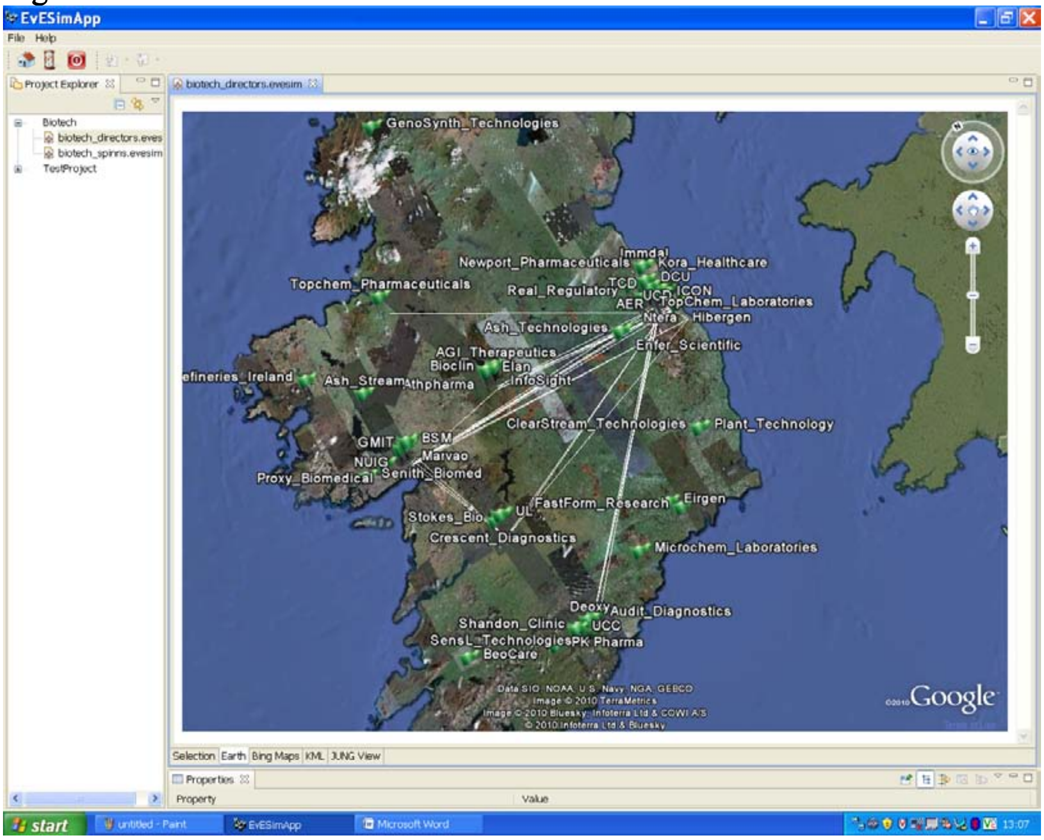


Figure 8.2: Screenshot visualisation network of directors



9 CONCLUSION

Task 11.6 set out to explore and explain the structures of knowledge flow and innovation among SMEs in the Irish biotech sector. In particular, the study addressed three main research questions: (1) What are the structural characteristics of knowledge and innovation networks in the Irish biotech sector and are these conducive to knowledge flow? (2) Are these networks exploited for local knowledge flow (3) What does this mean for the role of a biotech digital ecosystem and its contours?

The first research question was addressed through quantitative social network analysis. The small world analysis of the informal network of company directors reveals that this network is characterised by short path lengths and high clustering. This type of structure is conducive to knowledge flow. The formal network of researchers (patent data) is also characterised by high clustering and short path lengths. However, in this instance the company network is noticeably less clustered via patents than it was through directors. This indicates that that this formal network of researchers is conducive to knowledge flow although relatively less so than the informal network of company directors. The formal network of spin-off companies (emanating from both biotech companies and universities) exhibits no small world characteristics, which would indicate that the structure of this network is not conducive to knowledge flow.

The network data was also used to explore a number of spatial aspects of the biotechnology networks. The formal network of researchers was shown to have both national and global dimensions. These formal network data support the view that while the investigator network has a strong national component, the Dublin region, and even Ireland as a whole, should not be treated as "an isolated island of innovation". The informal network of company directors is far less global in character. This should however not be generalised to other informal networks in the biotech industry. It is true that the membership of most national professional and industrial organisations is nearly entirely national. However, the interviews undertaken in this study demonstrate that other informal networks such as the professional networks of individuals, the epistemic community and network of university alumni include a large international component.

Although a large part of the Irish biotech industry is concentrated in the greater Dublin Area, the directorship network is not bounded by the city-regional scale. Many directors of companies in Dublin have links with companies outside the city-region. Therefore, from a directorship network perspective, the relevant scale of the biotech ecosystem is national, rather than city-regional.

The geography of the spin-off processes is surprising. Existing theory and empirical accounts generally suggest that spin-off firms locate in the same region as the spinner firm, representing an important mechanism for localised industrial agglomeration and clustering. In the Irish biotech industry, although many of the spin-offs of Dublin-based institutions/firms established themselves in Dublin, a relatively large number of firms that spun off institutions/firms located outside Dublin, ended up in different regions, notably in Dublin. Therefore, although a large part of the industry is

concentrated in Dublin, we would argue that from a spin-off network perspective, the relevant scale of the biotech ecosystem is again national, rather than city-regional.

The social network analysis provides insights into the structure of the networks and their ability to support knowledge flow. However, the structures are only suggestive of knowledge flow. It remains unclear how much knowledge flows through the links and how far the knowledge actually flows through the network. It is therefore important to investigate what actually flows across the links (Grabher, 2006) – the extent to which the networks are exploited.

To answer this second research question, interviews were conducted with members of the various networks. The interviews show that the three particular networks under consideration are poorly exploited, although to different extents. With respect to the network of investigators (patents) we found no evidence of companies obtaining knowledge from either the directly or indirectly linked companies. The network of directors involves a greater amount of knowledge flow. Interestingly, apart from one case, the flows generally do not involve technical knowledge concerning the directly linked firms.

Most interviewees stated that their firms had received valuable general business and know-who type knowledge from their directors, including from those with multiple directorships. However, all but one of the interviewees argued that the link with the directorship network was of limited relevance. The knowledge generally involves the embodied knowledge of the director. It is difficult to assess the role of the directorship network for the accumulation of this embodied knowledge inherent in the director. What is clear though is that, for the focal firms themselves, the directorship network plays a relatively limited role in the identification of, and/or introduction to, relevant actors in the Irish market. The interviews show that the directorship network is merely one, relatively less important, network in a broader set of informal network relations connecting companies.

Interestingly, directorship networks do play a more important role at the international scale. A number of the interviewed companies have corporate interlocks with firms outside of Ireland and these are frequently used to obtain information about firms or markets abroad.

The interviews provided evidence of more substantial knowledge exchange in the third network, the network of spin-offs. The more formal spin-offs in the sample involved both technical and know who / market type knowledge and in both cases some of the knowledge was considered relatively important for the innovative performance of the firm. The less formal spin-off relations in the sample tend to involve lower levels of knowledge flow, and the flow tends to be limited to know-who and market related knowledge of limited strategic importance.

Apart from the firms linked by the three networks, the interviewed companies did obtain knowledge from other local firms. With respect to technical advice, all interviewed companies had been in contact with between three and nine other Irish companies/institutions. Universities were the main sources for technical knowledge. However, in general, the majority of cases involved very limited technical advice or knowledge flow. Most strategic links tend to involve universities.

Although some of these contacts started with a "cold call", we found evidence of informal networks facilitating the identification of the relevant actors. However, the number of instances of companies intentionally consulting other local companies for local know-who/business type knowledge, was relatively small. The relatively low level of intentional local know-who exchange is due to the fact that companies are relatively well informed about the local actors. This is not to say that networks play no role. The level of personally embedded know-who type knowledge is, in fact, largely a result of long term participation in local networks. In addition, the informal networks are strongly exploited for obtaining knowledge about actors in other countries.

A combination of, mainly informal, personal networks are at play, including professional networks of the individuals, student networks and social networks. Most important are the personal professional networks, built up over years, linking former and current colleagues and commercial contacts. Another important network is formed by university alumni. Apart from the personal networks, an increasingly important set of networks is created by the various industrial or research support agencies, including IDA, Enterprise Ireland, university tech transfer offices, Science Foundation Ireland, etc.

The findings are surprising, at least at first glance. The formal network of spin-offs turns out to be the most intensely exploited, notably for technical knowledge flow. This is the network that was considered least conducive to knowledge flow on the basis of social network analysis. The explanation for this apparent contradiction is that the knowledge flow tends to be contained between the spinner and the spin-off firm. That is, the level of diffusion to the broader industry is limited.

On the other hand, the network that was suggested to be most conducive to knowledge flow according to the social network analysis exercise, the informal network of company directors, appears to be strongly under-exploited - both for technical and know-who type knowledge flow. Two points need to be made here: First, the directorship network should not be interpreted as a separate network, functioning independently of all other networks. Rather it is part of a large integrated set of partly overlapping informal networks linking the Irish biotechnology firms. It is clear, though, that the directorship network is a relatively unimportant element in the overall informal network constellation. Other informal networks play a far greater role in knowledge flow.

Secondly, the fact that most (established) biotech companies make a lower than expected use of the informal networks for the active or intentional search for know-who type knowledge concerning the local industry does not mean that these networks are not exploited or not valuable. The Irish biotech industry is small and it is precisely due to the long-term participation in the local informal networks that most established actors are, and remain, (passively) informed about the relevant players in the local industry. In addition, the interviews do suggest that less established firms do rely more strongly on their informal networks for know-who type knowledge and introductions to local actors. Finally, the informal networks do play a significant role in (intentionally) obtaining know-who type knowledge about non-local actors.

The insights into the structural characteristics of the knowledge and innovation networks, and the actual level of knowledge flow, of the Irish biotechnology sector yield important lessons regarding the roles and contours of a biotech DE. Based on these insights we can confirm many of the ideas expressed in earlier OPAALS Deliverables on this topic, as well as add a number of further ideas:

- The results confirm that, rather than focussing on individual formal networks, the biotech DE should involve the entire social worlds of firms - the entire constellation of informal social networks, including professional networks of individuals, university alumni, and social networks.
- A biotech DE can play a valuable role in facilitating the flow of know-who and business/market type knowledge related to Ireland, particularly benefitting new, less established, firms. It will be of limited benefit to established firms. This can involve the exploitation of existing informal network links and the stimulation of new network links.
- A biotech DE can play a particularly valuable role in stimulating the flow of know-how and business/market type knowledge related to foreign locations. This can also involve the exploitation of existing informal network links and the stimulation of new network links.
- Existing informal networks in the biotech industry involve limited technical knowledge flow and diffusion, mainly due to efforts to protect firm-specific knowledge and intellectual property. There is however scope to better exploit the informal network for the flow of non-sensitive technological knowledge.
- The central importance of universities as the principal source of technical knowledge suggests that a biotech DE should specifically aim to facilitate the development and exploitation of formal and informal networks involving these universities.
- The analysis of the various networks suggests that the Irish biotech ecosystem functions at a national scale. Although many firms are spatially concentrated in the Dublin area, the firm are part of a national ecosystem. A biotech DE in Ireland should therefore be structured on a national, rather than a regional scale

To further distil these lessons and ideas for actual biotech applications, interviews were conducted with members of the biotech community and industry experts and a focus group meeting was organised to solicit the ideas of the biotech community. Based on the results of the network analysis, the interviews and the focus group meeting, we believe that the following applications have the greatest potential to kick-start a biotech DE in Ireland:

- A forum for regional actors (in universities; research institutions and private enterprise) to consult each other on a reciprocal basis about the location of (regional and extra-regional) actors, sources of knowledge and relevant intellectual property. This forum would involve a network visualisation tool which identifies national and international connections of actors. This idea is illustrated in the next section.

- A regionally-based science forum for biotechnology scientists and technicians. Here biotechnology scientists and technicians in companies and universities could ask for advice about, and interactively discuss, scientific and technical problems.
- A biotechnology sector-dedicated electronic interactive labour exchange, matching skilled people to jobs.
- A directory tool, providing information about and promoting regional actors, as well as promoting Ireland as a biotech region.

Building on these research findings, a further OPAALS research exchange project contributed to the development of a tool that could become part of the suggested forum for regional actors – a network visualisation tool. This visualisation tool could play an important role in identifying connections of potential partners in Ireland and abroad. This could allow actors to identify common contacts who may provide helpful introductions.

BIBLIOGRAPHY

Arundel, A. Beuzekom, B. van and Gillespie I. (2007) Defining Biotechnology Carefully, *Trends in Biotechnology*, 25(8), pp. 331-332.

Asheim, B. and Gertler, M. (2005) The Geography of Innovation. In: J. Fagerberg, D. Mowery and R. Nelson, *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

Asheim, B., Vang-Lauridsen, J. and Coenen, L. (2006) Face-to-Face, Buzz and Knowledge Bases: Socio-Spatial Implications for Learning, Innovation and Innovation Policy, *Environment and Planning C.*

Asheim, B., Coenen, L. and Vang, J. (2007), Face-t-Face, Buzz and Knowledge Bases: Socio-spatial implications for Learning*, Environment and Planning* C 25(5), pp. 655-670.

Arita, T. and McCann, P. (2000) Industrial Alliances and Firm Location Behaviour: Some Evidence from the US Semiconductor Industry. *Applied Economics* 32, pp. 1391-1403.

Asheim, B., R. Boschma and Cooke, P. (2007) *Constructing regional advantage: platform policy based on related variety and differentiated knowledge bases*. Utrecht University Working Paper.

Bathelt, H. Malmberg, A. and Maskell, P. (2004) Cluster and Knowledge : Local Buzz, Global Pipelines and the Process of Knowledge Creation, Progress in Human Geography, 28 (1), pp. 31-56.

Brink, J., McKelvey, M. amd Smith, K. (2004) Conceptualising and Measuring Modern biotechnology. In: McKelvey, M., Rickne, A. and Laage, J. The Economic Dynamics of Modern Biotechnology. Cheltenham: Edward Elgar

Boschma, R. (2005) Proximity and Innovation: A Critical Assessment. *Regional Studies* 39, pp. 61-74.

Bruland, K. and Mowery, D. (2005) Innovation Through Time. In: J. Fagerberg, D. Mowery and R. Nelson, *The Oxford Handbook of Innovation*. Oxford: Oxford University Press, pp. 349-380.

Casper, S. and Murray, F. (2005) Careers and Clusters: Analyzing the Career Network Dynamics of Biotechnology Clusters. Journal of Engineering Technology Management, Vol. 22, pp. 51-74.

Chesbrough (2003) *Open Innovation*, Boston: Harvard Business School Press

Coenen, L., Moodysson, J., Ryan, C., Asheim, B. and Phillips, P. (2006) "Comparing a Pharmaceutical and an Agro-food Biorgeion: On the Importance of Knowledge

bases for Socio-spatial Patterns of Innovation". *Industry and Innovation*, 13(4), pp 393-414.

Cooke, P. (2001) Regional Innovation Systems, Clusters and The Knowledge Economy, Industrial and Corporate Change, 10(4), pp. 945-74.

Dahl, M. And Pedersen, C. (2004) Knowledge flow through informal contacts in industrial clusters: Myth or Reality, Research Policy 33, pp. 1673-1686.

Davis, G., Yoo, M. And Baker, W. (2003) The small world of the American corporate elite, 1998-2001. *Strategic Organisation* 1, pp. 301-26

Edquist, C. (2006) Systems of Innovation: Perspectives and Challenges. In J. Fagerberg, D. Mowery and R. Nelson, *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

Freeman, L. C. (1979) Centrality in Social Networks: Conceptual Clarification. Social Networks 1:215–39.

Gertler, M. (2008) Buzz without being there? Communities of Practice in Context. In: Amin, A and Roberts, J (eds.), *Community, Economic Creativity and Organisation.* Oxford: Oxford University Press, (forthcoming).

Grabher 2006, trading routes, bypasses and risky intersections: mapping the travels of networks , progress human geography, Progress in human Geography 30 (2), pp. 163-189.

Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology, 91*(3), pp. 481-510.

Gertler and Wolfe (2006) Spaces of Knowledge Flow: Clusters in a Global Context. In: Asheim, B., Cooke, P., and Martin, R., *Clusters and Regional Development: Critical Reflections and Explorations*. London: Routledge, pp. 218-236.

Ingstrup, M., Freytag, P. And Famgaard, T. (2009), Cluster initiation and development: a critical view from a network perspective. Paper presented at the *IMP 2009 Conference*, Marseille, 3-5 September 2009

Kogut, B. and Walker, G. (2001) The Small World of Germany and the Durability of National Networks, American Sociological Review, 66 (3), pp. 317-335.

InterTradeIreland (2003) *Mapping the Bio-Island*, Newry: InterTradeIreland.

Laage, J., McKelvey, M. and Rickne, A. (2004) Introduction. In: McKelvey, M., Rickne, A. and Laage, J., *The Economic Dynamics of Modern Biotechnology.* Cheltenham: Edward Elgar

Lazonick, W. (1991) *Business Organisation and the Myth of the Market Economy,* Cambridge: Cambridge University Press.

Lester, R and M. Piore (2006) *Innovation* Cambridge, MA: Harvard University Press.

Lundvall, B. (1992) *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning*, London: Pinter.

Lundvall, BA, B Johnson, ES Andersen, B Dalum, (2002) "National systems of production, innovation and competence building" *Research Policy* 31, 2, 213-231

Martin, R. and Sunley, P. 2003. Deconstructing clusters: chaotic concept or policy panacea? *Journal of Economic Geography* 3, pp. 5-35

Nachira, F., Nicolai, A., Dini, P., Le Louarn, M. and Rivera, L. (2007) *Digital Business Ecosystems,* Luxembourg: Office of the Official Publications of the European Communities.

Malmberg, A. and Maskell, P. (2002) The Elusive Concept of Localization Economies: Towards a Knowledge-Based Theory of Spatial Clustering. *Environment and Planning, A* 34, pp. 429-449.

Malecki, E. and Moriset, B. (2008) *The Digital Economy*. Abingdon: Routledge

Malerba, F. (2003) "Sectoral Systems: How and Why Innovation Differs Across Sectors" in J.Fagerberg et al *Handbook of Innovation*.

Mayer, H. (2009) "Entrepreneurship and Regional Development: A genealogy approach to understanding the evolution of high-tech regions". Paper presented at Centre for Innovation and Structural Change Seminar Series, NUI Galway, 30 April.

Milgram, S. (1967) The Small World Problem. Psychology Today, 2, pp. 60–67.

Millar, H. (200), Biotech's Defining Moments, *Trends in Biotechnology*, 25 (2), pp. 56-59.

Moodysson, J. (2007), *Sites and Modes of Knowledge Creation: on the Spatial Organisation of Biotechnology Innovation*, Lund: Lund University.

Moodysson, J. (2008), Principles and Practices of Knowledge Creation: On the Organization of "Buzz" and "Pipelines" in Life Science Communities, *Economic Geography*, 84(4), pp. 449-470.

Moodysson, J., Coenen, L. and Asheim, B. (2008) Explaining Spatial Patterns of Innovation: Analytical and Synthetic Modes of Knowledge Creation in the Medicon Valley Life Science Cluster, *Environment and Planning A*, Vol. 40, pp. 1040-1056

Moodysson, J. and Jonsson, O. (2007) Knowledge Collaboration and Proximity: The Spatial Organization of Biotech Innovation Projects. European Urban and Regional Studies, 14 (2), pp. 115-131.

Myint, Y.M. and Vyakarnam, S. (2004) "Multiple directorships in Cambridge hi-tech cluster: implications for policy and research.", Paper presented at the 27th Institute of Small Business Affairs National Conference

Myint, Y.M., Vyakarnam, S. and New, M.J. (2005) "Effect of social capital in new venture creation, the: the Cambridge high-technology cluster." Strategic Change, 14(3): 165-177

Oerlemans, L. and Meeus, M. (2005). Do organisational and spatial proximity impact on firm performance? *Regional Studies*, 39(1), pp. 89-104.

Owen Smith and Powel (2006), Accounting for Emergence and Novelty in Boston and Bay Area Biotechnology, In: Braunerhjem, P and Feldman, M. Technology-Based Industrial Development, Oxford: OUP, pp. 61

Owen Smith, J. and Powel, W. (2004) Knowledge Networks as Channels and Conduits: the Effects of Spillovers in the Boston Biotechnology Community. Organisation Science 15 (1), pp. 5-21.

Porter, M. (1990) The Competitive Advantage of Nations. London: Macmillan.

Porter, M. (1998) The Competitive Advantage of Nations. Basingstoke: Palgrave.

Powell, W. et al. (2005) "Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences" *American Journal of Sociology* 110: 1132-1205.

Pavitt, K. (2006) Innovation Process, in J. Fagerberg, D Mowery and R. Nelson (eds.), The Oxford Handbook of Innovation, Oxford: Oxford University Press.

Saxenian, A. (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128,* Cambridge, MA: Harvard University Press.

Storper, M. (1997) *The Regional World: Territorial Development in a Global Economy.* London: Guilford.

Storper, M. and Venables, A. (2004), Buzz: Face-to-Face Contact and the Urban Economy, *Journal of Economic Geography,* 4, pp. 351-370.

Ter Wal, A,. and Boschma, R. (2008) Applying Social Network Analysis in Economic Geography: Theoretical and Methodological Issues. Annals of Regional Science, 43 (3), pp. 739-756.

Torre, A. and Gilly, J. (2000) On the Analytical Dimension of Proximity Dynamics, *Regional Studies*, 34, 169-180.

Torre, A. & A. Rallet (2005) Proximity and Localization. *Regional Studies* 39, pp. 47–59.

Yamaguchi, K. (1994) The Flow of Information through Social Networks Diagonal-Free Measures of Inefficiency and the Structural Determinants of Inefficiency. Social Networks 16, pp. 57–86.

Van Egeraat, C. O'Riain, S. and Kerr, A. (2009) Social and Spatial Structures of Collaboration and Innovation in the Knowledge Economy. Deliverable 11.2 for EU FP6 OPAALS Research Project, http://wiki.opaals.org/DeliverableAbstracts.

Van Egeraat, C. and Curran, D. (2010a), Social Network Analysis of the Irish Biotech Industry: Implications for Digital Ecosystems. In: Dini, P., *Digital Ecosystem*s, Springer (forthcoming)

Van Egeraat, C. and Curran, D. (2010b) Social Network Analysis of the Irish Biotechnology Industry: Implications for Digital Business Ecosystems. Paper presented at The Third International OPAALS Conference on Digital Ecosystems, Aracaju, Brazil, March 2010.

Van Egeraat, C. and Curran, D. (2009), Knowledge Flows and Networks in the Irish Biotech Industry. Paper presented at the workshop Planning a Digital Ecosystem for the Biotech Industry, Dublin Regional Authority, 3 November 2009.

Wasserman, S. and K. Faust (1994) Social Network Analysis: Methods and Applications. New York: Cambridge University Press.

Watts, D. (1999) Networks, Dynamics, and the Small-World Phenomenon. American Journal of Sociology 105, pp. 493-527.
Watts, D. and S. Strogatz (1998) "Collective Dynamics of 'Small World' Dynamics." Nature 393:440-42.White, H. (1970) "Search Parameters for the Small World Problem." Social Forces 49, pp. 259–64.

White, H. (1970) Search Parameters for the Small World Problem. Social Forces 49, pp. 259–64.

APPENDIX 1

KNOWLEDGE FLOW IN IRISH BIOTECH NETWORKS – INTERVIEW GUIDE

OPAALS RESEARCH TASK 11.6 – STRUCTURES OF KNOWLEDGE FLOW AND INNOVATION IN THE KNOWLEDGE ECONOMY: TOWARDS THE DEVELOPMENT OF A BIOTECH DE IN IRELAND

General Information:

Date of interview:

Name of firm: Firm number:

Address of firm:

Name of respondent:

Function of the respondent:

Part 1: Introduction

1) In what year was your firm established? In case of merger or acquisition, indicate also the year in which the most recent merger or acquisition took place.

2) Is your firm owned by another organisation?

3) Could you please indicate how many employees (full-time equivalents) are working in your firm?

4) What are the main activities for achieving competitiveness of your firm (multiple selections possible)?
    a. Production of tailor made products / processes for individual customers
    b. Production of standardised products / processes
    c. Product/process development
    d. Design
    e. Marketing
    f. Other…

Part 2: Discussion Socio-grams

Firm network linked by directors:

1) Did your firm obtain knowledge from directly linked firms
   a. What was the type of the knowledge (technical, know who, market)
   b. What was the importance of the various types of knowledge for innovative performance (1 -5 = very important)
   c. Please describe the process of flow

2) Did your firm obtain knowledge from indirectly linked firms (flow between three or more companies?)
   a. What was the type of the knowledge (technical, know who, market)
   b. What was the importance of the various types of knowledge for innovative performance (1 -5 = very important)
   c. Please describe the process of flow
   d. What is the maximum number of steps

Firm network linked by co-inventors:

3) Did your firm obtain knowledge from directly linked firms
   a. What was the type of the knowledge (technical, know who, market)
   b. What was the importance of the various types of knowledge for innovative performance (1 -5 = very important)
   c. Please describe the process of flow

4) Did your firm obtain knowledge from indirectly linked firms (flow between three or more companies?)
   a. What was the type of the knowledge (technical, know who, market)
   b. What was the importance of the various types of knowledge for innovative performance (1 -5 = very important)
   c. Please describe the process of flow
   d. What is the maximum number of steps

Part 3: Knowledge Exchange – Technological Knowledge

This part of the interview deals with the exchange of technological knowledge.

Record answers in separate matrix document [*not included in report*]

5) If you are in a critical situation and need technical advice, to which of the local organisations have you turned. These may be firms, universities, research organizations, public agencies etc.

6) Could you provide for each of the organizations mentioned above the following information:

   a. Please indicate the name and the type of organization. For firms specify whether they are suppliers, customers, competitors, other companies.
   b. How is this organisation linked to your organisation (in case of informal links, which persons are linked and how was contact established)
   c. Please indicate the location (municipality) of each organization you mentioned.
   d. Please indicate for each organization from 1-5 how important this relation is for your firm's innovation performance (1 not important to 5 very important).
   e. Please mention for each organization in which sector it is mainly active.
   f. Please mention for each organization whether the technological knowledge in your firm is similar to that of the organization mentioned. (1 not similar to 5 very similar)

7) To which non-local organisations have you turned [and follow-up questions as above]

8) Which of the following local organisations do you think have benefited from technical support provided from this firm? [Same set of follow-on questions]

9) Which organisations has this firm collaborated with in research projects in the last 2 years?

10) Could you express from 1 to 5 the importance of the following sources of information for gathering technological knowledge?
    a. Fairs and exhibitions
    b. Specialised magazines
    c. Market surveys
    d. Academic journals
    e. Are there any other sources of technological knowledge that are not mentioned above?

Part 4: Knowledge Exchange – Know Who / Market Type Knowledge

This part of the interview deals with the exchange of know-how and market knowledge, e.g. knowledge concerning new developments, market trends, market development, etc.

Record answers in separate matrix document [*not included in report*]

11) If you are in search of know-who / market type advice, to which of the local organisations have you turned. These may be firms, universities, research organizations, public agencies etc.

12) Could you provide for each of the organizations mentioned the following information:

    a. Please indicate the name and the type of organization. For firms specify whether they are suppliers, customers, competitors, other companies.
    b. Please indicate the location (municipality) of each organization you mentioned.
    c. Please indicate for each organization from 1-5 how important this relation is for your firm's innovation performance (1 not important to 5 very important).
    d. How is this organisation linked to your organisation (in case of informal links, which persons are linked and how was contact established)
    e. Please mention for each organization in which sector it is mainly active.
    f. Please mention for each organization whether the market knowledge in your firm is similar to that of the organization mentioned. (1 not similar to 5 very similar)

13) To which non-local organisations have you turned [and follow-up questions as above]

14) Could you express from 1 to 5 the importance of the following sources of information for gathering market knowledge?
    a. Fairs and exhibitions
    b. Specialised magazines
    c. Market surveys
    d. Academic journals
    e. Are there any other sources of technological knowledge that are not mentioned above?

15) Which of the following local organisations do you think have benefited from Know Who / Market knowledge provided from this firm? [Same set of follow-on questions]

Part 6: Possible role of Biotech DE

16) Please discuss your ideas regarding the possible role of a DE in the Irish biotech industry.