HTSF Conference Twente 2006

Unravelling Knowledge Networks of Urban High-Technology Firms: An Artificial Intelligence Approach

Marina van Geenhuizen, Associate Professor
Faculty of Technology, Policy and Management
Delft University of Technology,
Delft, The Netherlands, m.s.vangeenhuizen@tbm.tudelft.nl

Abstract
In urban innovation studies, much attention has been paid to benefits from local knowledge exchange for small high-technology companies. Much less attention has been given to the global pattern of knowledge networks. In this paper, we explore the spatial pattern of knowledge networks of young, innovative companies in urban areas in the Netherlands empirically, against the background of the debate about the role of spatial proximity in facilitating local knowledge exchange and learning processes. In this debate, the idea is challenged that tacit knowledge is confined to local places in providing unique advantages of knowledge spillovers to locally embedded companies. First, on the basis of conceptual notions from resource dependence theory and by using rough set analysis as a relatively new modelling approach derived from the field of artificial intelligence, we identify the factors that determine the spatial patterns of knowledge networks. Secondly, by taking the largest biotechnology cluster in the Netherlands as an example we examine to what extent companies in a clustered location employ regional and global networks and enjoy local knowledge spillovers among other agglomeration advantages.

KEY WORDS: Innovative companies, urban agglomeration advantages, knowledge networks, rough set analysis, biotechnology, the Netherlands.

1. DRIVERS OF THE URBAN ECONOMY AND PROXIMITY

It is common place that the capability to produce and utilize new knowledge is the most important asset of developed economies in Western Europe in their attempts to innovate and remain competitive. A major explanation for today's attention for this capability is the increased mobility of capital and labour, in a world in which modern traffic and communication technology and the disappearance of particular borders have led to an increased global competition (OECD, 1996). More specifically, it is the lagging behind of European countries in terms of major economic indicators, compared with emerging Asian economies and the US. In this context, new knowledge not only refers to new products and processes, but also to new markets and management models.

In recent studies on innovation of urban economies much attention has been paid to knowledge as an important component of agglomeration advantages. Companies that are drivers of the urban economy, that is young and competitive ones creating new jobs on the basis of information and communication technology (ICT), multimedia, biotechnology, material science, optics, laser technology, etc. are often seen as enjoying the benefits from locally embedded knowledge networks in their urban production environment. In this vein, cities provide advantages of knowledge spillover effects and an abundant availability of knowledge workers in the labour market (Acs, 2002; Audretch, 2000). Spatial concentration of similar and/or dissimilar activities increases the opportunities for interaction and knowledge transfer, and the resulting spillover effects reduce the cost of obtaining new knowledge. In addition, knowledge workers preferably interact with each other in agglomerated environments to reduce interaction costs, and they are more productive in such environments (Florida, 2002). The facilitation of face-to-face contacts and repeated meetings in person by spatial proximity and the limits to this by particular geographic borders, e.g. of a daily activity system or central business district, are central in the arguments of some authors to view tacit knowledge transfer and knowledge spillovers as being confined to local agglomerated environments (e.g. Maskell and Malmberg, 1999; Storper and Scott, 1995; Rosenthal and Strange, 2001). An exclusive availability of tacit knowledge and knowledge spillovers has been proposed – in urban agglomeration and cluster approaches - as the main mechanism that makes it beneficial for companies to be located in agglomerated urban areas and spatial clusters.

By contrast, much less attention has been given to global patterns of knowledge creation and use - like in biotechnology and nanotechnology. It is often overlooked that the need for high levels of competence and specialization may urge knowledge workers to participate in knowledge networks within strategic alliances across the globe on the basis of face-to-face contact. Also, the position as a subsidiary of a foreign mother company may cause a frequent participation in knowledge networks abroad. The attention for achieving tacit knowledge at distant places, through personal visits or detach of knowledge workers, is relatively new (e.g. Rutten and Boekema, 2004; Doornbos, 2005) and puts an emphasis on access of urban places to an international airport (Simmie and Sennett, 1999). The crucial condition in the exchange of diffuse and tacit knowledge in this view is a similar social context of the partners involved, determining a proper understanding and interpretation of the knowledge. There are some recent attempts to connect the two views and understand the conditions under which knowledge is exchanged locally and globally (e.g. Bathelt et al., 2004). This paper fits into this recent trend. Accordingly, the aim of this paper is to explore and understand the spatial layout of knowledge networks and benefits from knowledge spillovers and other agglomeration advantages of innovative companies in urban places. To this purpose, we examine the following questions: (1) To what extent are urban innovative companies utilizing regional and global networks in knowledge exchange and learning? (2) What factors determine the spatial layout of these networks? (3) What is the importance of local knowledge spillovers among other advantages of an agglomerated location?

The structure of the paper is as follows. We first address notions from resource dependence theory to better understand the needs of young, innovative companies, and pay attention to some theoretical aspects of knowledge networks (section 2). This is followed by a discussion of the research design, particularly the use of rough set analysis (section 3). Next is the interpretation of empirical results on the spatial layout of knowledge networks (section 4) and a more in-depth analysis using a case study of clustered biotechnology companies (section 5). The paper concludes with a summary and evaluation of the empirical results in the light of the debate, and indicates some future research paths.

2. A BRIEF THEORETICAL INTRODUCTION

In this section we briefly discuss some essential notions from resource dependence theory, particularly to increase understanding of inter-firm differences in opportunities and sets of resources among young, innovative companies (Barney, 1991; Reid and Garnsey, 1998; Richardson, 1972). In addition we focus on theoretical aspects of networks and knowledge networks, as a specific kind of resource.

In modern versions of resource dependence theory companies are seen as bundles of resources with their long-term competitiveness resting in resource configurations that managers build. Companies make use of various combinations of resources (bundles) on a temporary base, like knowledge, capital, employees and networks, and their success depends on their capability to match opportunities with the development of own resources or disclosure of external resources. Growth is constrained if there is a shortage or weakness in the companies' capability to generate internal resources and if companies lack the capability to disclose external resources. With regard to the growth of young, high-tech companies, Reid and Garnsey (1998) distinguish between three different stages, running from achieving access to resources, mobilisation of resources, to the own generation of resources. Knowledge is a critical resource in all three stages, including knowledge on commercial opportunities, on the business start-up process, and on business development, marketing and finance, respectively.

Knowledge is not only about know-what and know-how, but also know-who and know-why (e.g. Lundvall and Johnson, 1994). This classification of subject matter is often associated with different types of knowledge in terms of codification and transferability (e.g. Gorman, 2002). Accordingly, know-what and know-why mainly refer to codified knowledge found in manuals, data-basis, and conference proceedings, etc., whereas know-who and know-how are mainly connected with practical experience, learning-by-doing and social interaction including the transfer of tacit knowledge. Unlike codified knowledge, the creation and use of tacit knowledge is strongly dependent upon the social and organizational context that determines - through shared beliefs, perceptions and experiences – understanding and interpretation (e.g. Gertler, 2003). Note that the various types of knowledge do not work separately, but interact in processes of learning. For example, tacit knowledge is necessary to understand codified knowledge.

The use of the right combination of resources at the right time enables companies to undertake a jump in their growth (next development stage) (Vohora et al., 2004). Most recently, a stronger emphasis is put on heterogeneity between high-technology start-ups at their start in terms of opportunities and resource requirements, e.g. following from a different position of the entrepreneur, a different corporate position (independent company, support form mother company, etc.) and different main activities, like contract R&D, in-house basic research and technical services (e.g. Druilhe and Garnsey, 2004).

Networks can be seen as a specific external source of resources that may be utilized to exploit opportunities (e.g. Brush, 2001). Analysing entrepreneurship from a network perspective has become quite fashionable since the mid 1980s in organizational and economic studies (e.g. Borgatti and Foster, 2003; Hoang and Antoncic, 2002; Kamann, 1989). Networks can be perceived as a set of actors connected by a set of ties, the former including persons, teams or organisations (Granovetter, 1973). Companies establish networks or they decide to participate in existing networks if the perceived benefits outweigh the costs concerned. To achieve the best knowledge may be the main purpose of a network (e.g. a strategic alliance on R&D) or is a positive side-effect of other networks, like the ones with customers in which products or processes are adapted on customer demand. Networks face many dimensions aside from their spatial layout (e.g. Hoang and Antoncic, 2002; Kamann, 1989):

- tightness of the ties, like loosely coupled or tightly coupled ones;
- strength of the ties, like strong or weak ties;
- directed or non-directed ties, like a personal advice to a network member, or shared facilities for all members due to e.g. physical proximity;
- structure of the network, like one-to-one networks and multiple focal networks;
- stability, like temporary networks and (semi) permanent networks;
- a set of other characteristics, like level of institutionalisation, hierarchy involved, symmetry involved, formal nature, etc.

Knowledge networks face all the above dimensions and differences. For example, knowledge networks in medical biotechnology may encompass rather long lasting, one-to-one relations in research project and employ knowledge exchange in a formalized manner. By contrast, networks in software design may be equally one-to-one, but last for just one design project, and the knowledge may be highly diffuse and tacit e.g. to solve badly structured customer problems. The above notions and views call for a thorough empirical investigation. The next section discusses the design of the empirical study.

3. RESEARCH DESIGN

The research design of this study employs an inductive approach using a limited number of carefully selected case studies. The case study design permits a logic in the sense of "replication", allowing the case analysis to be treated as a series of independent experiments (Yin, 1994).

The study utilised a detailed field study of 21 young, innovative companies in the Netherlands, selected from biotechnology, ICT-services and mechatronics (optronics). Data were derived from face-to-face interviews with corporate managers and, additionally, from web presentation and annual reports of companies, and from branch reports and journals of the various sectors. The research design required the use of a semi-structured questionnaire in the interviews, to produce both scores in a standardised way and in-depth insights; the latter to obtain a rich understanding of the spatial knowledge network and relevance of international airports on the individual level. The research design also implied that companies were selected to contain a substantial degree of variance on dimensions that are relevant from a resource-dependence perspective, e.g. company size, position and degree of innovativeness. For example, in the biotechnology sector we selected genuine research companies (long development paths of new medicines), companies involved in tool development (platform technologies), and service companies (shorter innovation projects) (Biopartner, 2002).

Information from the semi-structured interviews was used to develop a database as a matrix of objects (companies) that constitutes a concise representation of the underlying field information: the information table. We developed such a table (see Appendix 1), i.e. to serve as a basis for a systematic analysis of knowledge networks and determining factors. In our study, conventional statistical analysis (such as multiple regression analysis or discrete choice modelling) could not be applied because of the low level of measurement of some variables (categorical) and the small sample. We, therefore, made use of another technique that has increased in attention in the past years as a pattern recognition or classification technique, i.e. rough set analysis (e.g. Pawlak, 1991; for details, Polkowski and Stolron, 1998). An additional advantage is that in rough set analysis - unlike more conventional methods – only one assumption is made about the data, i.e. that the value of the determining factors can be categorized. Rough set analysis works as follows. If in a causal investigation a distinction can be made between stimuli (*condition variables*) and response (*decision variable*), then rough set analysis is able to identify causal linkages between classified conditions and decision variables. In our analysis we are particularly interested in the decision algorithms produced by a stepwise scanning of the data-matrix. These contain conditional statements of an "if ….., then ..…." nature. Accordingly, we can identify which conditions (combinations of attributes of the conditional variables) lead – in a logic deterministic way - to a particular state of the decision variable. The decision variable in our study is the spatial pattern of knowledge networks. A useful computer software programme to carry out a rough set analysis is Rough Set Data Explorer (ROSE). This algorithm constructs the best possible decision rules to explain the frequency of occurrence of features. Further details can be found in the aforementioned references.

Knowledge networks were measured as "relations dealing with knowledge", e.g. concerning personal networks of the manager (CEO), customers, suppliers, knowledge institutes, alliance partners, head office, etc. In our approach of emphasizing interpersonal networks, tacit knowledge forms a substantial part of the knowledge concerned. In addition, the more stable relations were included. The knowledge relations identified could cover ego-centred networks (like between the company and a research group at the university in a dedicated project) as well as multiple focus networks (like between the company and customers with multiple customer relations). We have measured the spatial pattern of knowledge networks on the basis of revealed preference, i.e. the most important current knowledge sources for innovative activities and the location of the relationships involved. We could have chosen other ways to measure knowledge relations (networks), e.g. on the basis of joint patent applications or patent citations, but this would have narrowed our scope because much knowledge exchange (and spillovers) happens independent of patent activity.

The condition attributes were selected on the basis of the previously indicated resource-based approach. Accordingly, these attributes refer to a different profile of companies in terms of knowledge requirements and access to external knowledge, such as current position (spin-off, subsidiary, independent, etc) and age. With regard to the latter, we wanted to capture really young companies, still vulnerable for some starting-up failures, and older ones that survived this period (but not older than 15 years). We also included size of the company, main activity (manufacturing or services) and development time of innovations. Using the latter, we attempted to capture different levels of innovativeness and related knowledge requirements. As an indicator for the level of innovativeness, we could also have taken the number of granted patents. However, patenting as a strategy to protect intellectual ownership is less common in services than in manufacturing and would have given a wrong impression of innovative activity in services. Furthermore, we added the generic spatial orientation of the company, as measured based on the company's dominant supplier and customer relationships. The condition attributes can be summarized as follows: 1) corporate position (status); 2) age; 3) size (employment); 4) main activity; 5) development time of innovations; 6) general spatial orientation.

The rough set procedure provides results that assess the *quality of the data* (condition variables and dependent variable) in the information table. First, each estimation produces a distinction between "core variables" and other variables. If all condition variables belong to the core, then the conclusion can be drawn that all these variables contribute to an explanation and no variable gives redundant information. In our analysis, all but one condition variable belong to the *core*. The quality reaches the value of 1.0, meaning that the reliability of the classification for the dependent variable and the overall quality of the information table are at their maximum (see Appendix 2). Further, each rough set analysis produces a number of decision rules and for each rule the concomitant coverage (in percentages). The coverage is an indicator of the strength of the rule, calculated as the share of the cases with a similar set of attributes and score on the decision variable divided by all cases with this score on the decision variable. The highest level reached in our analysis is 41.7% (5/12). Another indicator that can be used in the interpretation of rough set results is the frequency in which a condition variable is included in the set of rules. Note that the interpretation of the results of the rough set analysis is valid to the extent in which the case studies selected provide a fair representation of young, innovative, companies located in the major city-regions in the Netherlands. In the next section we proceed with a discussion of the rough set results.

4. SPATIAL LAYOUT OF KNOWLEDGE NETWORKS

We present the results of a comparative analysis of the companies in two parts. First, we discuss the different spatial patterns of the knowledge networks and secondly, we examine the results of the rough set analysis in explaining these patterns.

We have determined the spatial layout of the knowledge networks on the basis of the location of each of eight relevant knowledge sources for innovative activities, i.e. personal networks, customers, suppliers, universities (other knowledge institutes), partners in alliance, other parts of company (mother company, subsidiaries), conferences and fairs. A company was classified "mainly regional" if the share of regional networks is larger than the share of global networks, and "mainly global" if the share of global networks is larger than the share of regional networks. We adopted this classification because a more refined classification would have led to more classes (note 1). Four or five classes would have rendered rough set analysis as a broad pattern recognition technique less useful.

Table 1 shows the characteristics of the sample in terms of the spatial layout of the knowledge networks. First, it appears that particular segments of young innovative companies in urban areas employ mainly regional networks while other segments employ mainly global networks. There is thus clearly a trend for *co-existence*. Secondly, the global networks seem to have developed in a more pronounced way compared with the regional networks, witness the differences in maximum shares (100 versus 58%).

Table 1 Descriptive statistics of knowledge networks a)

	Mainly regional	**Mainly global**	**Total**
Nr of companies	9	12	21
Average share of region (%)	38	-	22
Max share of region (%)	58	-	58
Average share of global (%)	-	57	38
Max share of global (%)	-	100	100

a) 21 case studies

The application of the rough set methodology has led to a set of eleven decision rules referring to the above two classes of spatial layout. In the remaining section, we limit our discussion to eight rules that are solid in that they cover companies not subject to an exceptional situation (ICT crisis). The results can be summarized as follows (Table 2, see, also Appendix 2):

1. Two factors have a strong influence on the spatial layout of knowledge networks, i.e. position (status) and general spatial orientation (customers/suppliers). Other factors derived from resource dependence theory, like age and size, are less important.
2. If we focus in on global networks, the most determining factors are position (status) and duration of innovation projects. This points to an important influence of corporate ownership relations and the level of innovativeness (specialization). The knowledge networks mainly include worldwide customers and research alliances.
3. A relatively strong rule is Rule 7, referring to global networks and covering 5 companies (41.7%). This rule is particularly strong because it includes companies from different sectors (biotechnology research and advanced optronics development and manufacturing). In addition, a closer look reveals that the companies are rather homogeneous in share of global networks, i.e. a range between 42 to 70%.
4. If we consider how the rules relate to economic (sub)sectors, it becomes clear that all the three sectors (ICT services, biotechnology and optronics industry) are present in both classes, pointing to a weak importance of the sector.

We may conclude that young, innovative companies in urban regions tend to derive essential knowledge only partly from this region. Broadly, there are two segments: (a) companies with a predominantly regional network based on strong knowledge ties with local customers or suppliers and (partly) advanced ICT facilities, and (b) companies with a predominantly global network influenced by network configurations of the mother company or company of origin, or a high level of innovativeness (specialization) urging to connect globally.

Table 2 Rough set results on the spatial layout of knowledge networks

Condition variables	**Nr of cases and strength of rules**	**Rules and additional information (italics)**
Mainly Regional		
Size and general spatial orientation	2 (22.2%)	Rule 1: Medium-sized/larger and a local orientation *ICT services (specialized call centres and IT facility providers)*
Position and general spatial orientation	2 (22.2%)	Rule 2: Independent position and local orientation *Services in biotechnology (testing)*
Position and duration of innovation projects	2 (22.2%)	Rule 3: Academic spin-off and short lasting innovation projects *Non-standard ICT services*
Age, main activity type, general spatial orientation	2 (22.2%)	Rule 4: Young manufacturing companies without preference in orientation *Young companies in advanced optronics industry in stage of (re)start*
Mainly Global		
Position and general spatial orientation	3 (25.0%)	Rule 5: Independent or foreign subsidiary, without preference in orientation *ICT services and engineering services*
Position and main activity type	1 (8.3%)	Rule 6: Corporate spin-off and providing services *Advanced biotechnology services (process optimisation) and network from multinational (origin)*
Age and duration of innovation projects	5 (41.7%)	Rule 7: Older age and (very) long lasting innovation projects *Biotechnology research and advanced optronics development*
Age and general spatial orientation	2 (16.7%)	Rule 8: Young age and global orientation *Biotechnology research (foreign subsidiary) and ICT services (digital protection software design)*

Source: Adapted from van Geenhuizen, 2005.

In a next step, we attempt – as a preliminary experiment - to apply the rules derived from the rough set analysis to a small population of companies.

5. KNOWLEDGE NETWORKS IN A BIOTECHNOLOGY CLUSTER

In order to apply the above rules to a small, clustered, population of companies, we have selected the biotechnology sector and one particular cluster in the Netherlands, i.e. the region of Leiden. In order to find data concerning the condition attributes, we made use of sector reports on biotechnology in which most companies are listed (Biopartner, 2003, 2004; Holland Biotechnology, 2003). Official statistics could not be used because medical biotechnology – the specialization of the cluster in Leiden - is not clearly visible or dispersed in such statistics.

The biotechnology cluster of Leiden is located in-between the agglomerations of The Hague and Amsterdam. Its origin goes back to the early 1980s. Driven by the inspiration of some leading academics (molecular biology) and visionary views of local policymakers in the early 1980s, the municipality opened the Bio-Science Park in 1984, including an incubator facility as a joint initiative with the university. Growth of the park took off almost immediately, after the establishment of a subsidiary of US-based *Centocor* in 1985. Early 2004, the number of biotechnology companies amounted to about 30, including young entrepreneurial companies and foreign subsidiaries, but excluding consultancy companies and traditional pharmaceutical industry. The knowledge institutes in the cluster encompass various faculties of the State University of Leiden (including its medical school and academic hospital), the Higher Educational Institute Leiden, the Leiden School for Instruments Design, TNO Applied Sciences in Prevention and Health, the Center for Human Drug Research (clinical research cooperation of the universities of Leiden and Amsterdam), and the Center for Medical Systems Biology (Genomics). Delft University of Technology (about 30 km South) provides hard-core technology, like in bio-process technology, and is involved in joint educational programs with the University of Leiden in life sciences.

Our assumption in the application of the rough set rules to companies clustered in Leiden is that the predictive power of the rules is 100%. Of course, the predictive power is lower. In other research, based on additional random samples drawn from the base population the accuracy in predicting the outcomes on the decision variable by information from the rules amounts to 75 and 87%, indicating a sufficient level of robustness (Goh and Law, 2003; Soetanto and Van Geenhuizen, 2005). In such extension of the analysis data need to be available for many more objects than merely those in the selected sample, which may hinder such approach. Further, in terms of difficulties encountered in classifying the companies according to the rules, we need to mention the following. First, information on the general orientation of companies, based on dominant supplier - and customer relations, is often not available in sector reports. In this respect, the information is derived from company websites and annual reports. Secondly, the main activity, e.g. research, services, manufacturing, is increasingly difficult to determine, due to a move by the companies to more hybrid models (Biopartner, 2004).

Given the above assumption and limitations, the knowledge networks in the biotechnology cluster in Leiden appear to be predominantly global in terms of employment concerned (91%) and but for a large part (56%) local in terms of number of companies (Table 3). This picture follows from a skewed size distribution of companies in the cluster, with a large number of small companies and a small number of large (often global) companies. In the remaining section, we discuss the outcomes of an in-depth analysis of biotechnology companies in the cluster of Leiden, to clarify this situation and connect networks to knowledge flows by using a more dynamic perspective (Cooke, 2004). In this perspective, a distinction is made between origin of the knowledge and check on viability (including the start-up company), and the stages of exploration, examination and exploitation, and places where the knowledge runs through these stages.

Table 3 Spatial knowledge networks in the cluster of Leiden (based on estimations)

Decisive company attributes	Dominant layout	Number of companies a)	Number of knowledge workers
Services, independently established, general regional focus	local	9	90
Research, very young start-ups (academic spin-offs)	local	6	35
Research, somewhat older age, and long-lasting innovation projects	global	8	405
Advanced services, general global focus	global	1	30
Foreign subsidiaries	global	3	+/- 800 b)
Totals (% share)	*local* *global*	*15 (56%)* *12 (44%)*	*125 (9%)* *1.235 (91%)*

a) Excluded are traditional pharmaceutical companies and consultancy.
b) The share of biotechnology knowledge workers in standardized production plants (mainly in *Centocor*) is estimated at 70%.

If we focus on research companies for which projects often last 10-15 years including testing and approval of new drugs and diagnostics - the following becomes clear. The viability of a new idea upon which spin-off companies from the university or academic hospital are based, is examined and checked locally in the cluster of Leiden. The new idea itself, however, may not originate exclusively from this cluster but also from nearby clusters (Amsterdam, Utrecht). In terms of advantages, start-up companies benefit from cheap and flexible laboratory room in incubators, shared facilities, easy contact with the medical school, academic hospital, and university, and a pool of specialized workers. Local knowledge spillovers play a *crucial* role in this stage. In the next stages, however, a further exploration and examination of the new knowledge increasingly take place outside the cluster of Leiden, in broader, mainly global networks, including big pharmaceutical industry and collaboration with medical schools, academic hospitals and research institutes. For example, development programs of *Crucell* include collaborations with *Aventis Pasteur*, the US National Institute of Health, *GlaxoSmithKline* and New York University. Accordingly, the knowledge networks have broadened and advantages now include easy access to the international airport of Amsterdam Schiphol (15-20 minutes time-distance from Leiden) and access to a super-computer. In these stages, a pool of specialized labour is only important if the company grows locally. Note that there are also some *practical* economies, i.e. services derived from nearby biotechnology service companies and the potential to pool laboratory facilities (e.g. clean rooms and breeding facility) and laboratory workers (analysts) during peak demand with a few neighbouring companies. Finally, the check for exploitation of the new knowledge also mainly occurs outside the Netherlands in global networks, in which big pharmaceutical and larger biotechnology companies dominate due to their marketing power.

What causes the above need to connect with global knowledge networks after a few years of existence, is the fact that in the cluster of Leiden - but also in a larger area, including the biotechnology clusters of Amsterdam and Utrecht – a strong basis of leading pharmaceutical and leading biotechnology companies is missing. The pharmaceutical companies here mainly produce *generics* or engage in standard production and packing of drugs, meaning a lower level of innovation and less interest in developing new drugs and diagnostics based on biotechnology. The biotechnology research companies in this region seem not sufficiently strong to take responsibility for the stage of exploration and the stage of testing and (clinical) trials. This situation makes the difference with what Cooke (2004) names “biotechnology megacentres”, like Boston, Cambridge (UK) and eventually Munich. However, the future for Dutch small biotechnology business is not that bleak. One of the Netherlands pharmaceutical/chemical companies is now quickly developing biotechnology as a core business and eager to cooperate with small companies in medical and food biotechnology, and that is *DSM*. Most recently, Leiden-based *Crucell* and Limburg-based *DSM* started cooperation.

The above spatial pattern of knowledge exchange among research companies is clearly different from the pattern among independent service companies, like the ones providing standard and customized testing (e.g. DNA sequencing; cleaning and validation studies). The knowledge involved has already successfully captured a place in the market and the knowledge networks are mainly regional on the basis of relationships with customers. Innovation has a different meaning here: mostly incremental improvements in testing and determination techniques on the basis of specific customer demand. Accordingly, local knowledge spillovers in the relation to customers matter for these companies. Other advantages of an agglomerated location include use of incubator facilities (start-up stage) and the potential of pooling capacity with selected neighbour companies. There is one type of service companies that does not fit into this picture, i.e. the one of which the networks have been modelled by an internationally oriented mother company. Most of the service companies in Leiden, however, do not match with this category.

We may conclude so far that in the start-up stage of biotechnology companies concerning drugs (diagnostics), local agglomeration advantages like knowledge spillovers from the local university and hospital are highly important. However, as soon as the knowledge networks become global after a few years, such local economies disappear and make place for easy access to global networks (mainly Amsterdam Schiphol Airport) and nearby (routine) knowledge services. The local knowledge institutes (university hospital, medical school, faculties) then become part of a larger, national and international network. This picture complies with some other recent research outcomes, indicating that overall, the local university (medical school) is not the prime source of information for clustered companies as the knowledge comes from more distance places (e.g. Lawton-Smith, 2004; McKelvey, 2004).

6. CONCLUDING REMARKS

The aim of this study was to increase understanding of the spatial dimension of networks through which young innovative companies located in urban areas create and exchange new knowledge. The theme fits into the debate about the importance of physical proximity in knowledge exchange, i.e. a crucial role in facilitating tacit knowledge transfer, versus no crucial role, but prime importance for social and organizational proximity, and concomitantly local knowledge networks versus co-existence of local and global networks. The results of this study support the idea of co-existence. In urban areas in the Netherlands we find segments of companies that have a global focus in their knowledge networks and segments that have a local (regional) focus. Furthermore, in a case study of a specific cluster –

biotechnology – we found a predominantly global focus based on employment data. Physical proximity (including local knowledge spillovers) in this cluster only matters in the context of spin-off processes from local knowledge institutes and in knowledge relations of service companies in the cluster. Partly, this situation can be ascribed to the absence in the cluster of pharmaceutical industry with which can be connected as well as the absence of a strong basis of regional biotechnology companies that can take the responsibility for further stages in the knowledge value chain, i.e. exploration, examination and exploitation of the new knowledge. Accordingly, connecting with global networks is a must for research companies after a couple of years.

Further research follows from the specific design of the current study. There is a need to carry out in-depth studies of the clusters that were only included in the rough-set analysis, e.g. ICT and mechatronics (optics) and to compare with biotechnology in terms of background to the regional and global networks, particularly how the new knowledge arises and where it is explored, examined and utilized. Another research line is methodological and concerned with the opportunities of rough set analysis. In our research design, we used a selected sample representative for particular types of companies. This means that the results cannot be generalised statistically. It would be interesting to undertake the selective sampling as a part of or partly aside from some random sampling, such that a connection (overlap) can be established between the random samples and the outcomes of rough set analysis (decision rules) can be randomised for a population. Such smart research designs (pooled structure) would then open ways to advanced modelling.

Acknowledgement
This paper benefits from support from TU Delft, as a part of the Spearhead Research Program "Sustainable Urban Areas" and from a grant of the Dutch National Science Foundation (project number: 014-43-616-P).

Note 1
We could have distinguished a third class: both regional and global companies. However, there were only two companies for which the share of the regional network and that of the global network were approximately equal in size.

References
Acs, Z. J. (2002), *Innovation and the growth of cities,* Edward Elgar, London.

Audretch, D.B. (1998) Agglomeration and the location of innovative activity, *Oxford Review of Economic Policy,* 14 (2): 18-29.

Audretch, D., 2001, "The Role of Small Firms in U.S. Biotechnology Clusters", *Small Business Economics*, 17: 3-15.

Barney, J. (1991) Firm resources and sustained competitive advantage, *Journal of Management* 17, 99-120.

Bathelt, H., Malmberg, A. and P. Maskell (2004) Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, 28 (1): 31-56.

Biopartner (various years) *The Netherlands Life Sciences Sector Report 2002-2004*.

Borgatti, S.P and P. Foster (2003) The network paradigm in organizational research. A review and typology. *Journal of Management*, 29 (6): 991-1013.

Brush, C.G., Greene, P.G., Hart, M.M. and H.S. Haller (2001) From initial idea to unique advantage; the entrepreneurial challenge to construct a resource base. *Academy of Management Executive* 15 (1): 64-78.

Cooke. P. (2004) The molecular biotechnology revolution and the rise of biosience megacentres in North America and Europe. *Environment and Planning C: Government and Policy,* 22: 161-177.

Doornbos, H. (2005) Mainport/Brainport? An explorative study of Schiphol Airport as a link between knowledge-based companies and global networks (MSc-thesis) (in Dutch). Delft/The Hague: TU Delft, Faculty of Technology Policy and Management and Ministry of Economic Affairs.

Druilhe, C. and E. Garnsey (2004) Do Academic Spin-Outs Differ and Does it Matter? *Journal of Technology Transfer*, 29 (3/4): 269-285.

Eisenhardt, K.M. (1989), Building theories from case study research. *Academy of Management Review*, 14: 488-511.

Florida, R. (2002), *The rise of the creative class, and how it is transforming work, leisure, community and everyday life*. New York, Basic Books.

Geenhuizen, M. van (2003) How can we reap the fruits of academic research in biotechnology? In search of critical success factors in policies for new-firm formation. *Environment and Planning C: Government and Policy*, 21: 139-155.

Geenhuizen, M. van (2004), Cities and Cyberspace: New Entrepreneurial Strategies. *Entrepreneurship and Regional Development*, January 2004: 5-19.

Geenhuizen, M. van (2005) *ICT, Location Dynamics and the Future of Cities*, Delft/The Hague: Delft University of Technology, Faculty of Technology, Policy and Management/Netherlands Science Foundation (www.nwo.nl/nwohome.nsf).

Gertler, M. (2003) "Tacit knowledge and the economic geography of context, or The undefinable tacitness of being (there)", Journal of Economic geography, 3 (1): 75-99.

Goh, C., and Law, R. (2003) Incorporating the Rough Sets Theory into Travel Demand Analysis, *Tourism Management* 24, 511-517.

Gorman, M.E. (2002) Types of knowledge and their roles in technology transfer. *Journal of Technology Transfer*, 27: 219-231.

Granovetter, M. (1973) The strength of weak ties. *The American Journal of Sociology*, 78 (6): 1360-1380.

Hoang, H. and B. Antoncic (2002) Network-based research in entrepreneurship: a critical review. *Journal of Business Venturing*, 17 (1): 1-23.

Holland Biotechnology (2003) *Life Sciences in the Netherlands. Genomics and Science Based Business.* Rotterdam: Holland Biotechnology.

Howells, J.R.L. (2002), Tacit knowledge, innovation and economic geography. *Urban Studies*, 39 (5): 871-884.

Kamann, D.J. (1989) Actors in Networks, in: Boekema, F.W.M. and D.J. Kamann (eds) *Socio-Economic Networks* (in Dutch). Groningen: Wolters-Noordhoff, pp. 29-84.

Lawton-Smith, H. 2004 The biotechnology Industry in Oxfordshire: Enterprise and Innovation, *European Planning Studies*, **12**: 986-1001.

Lundvall, B.A. and B. Johnson (1994) The learning economy, *Journal of Industry Studies*, 1 (2): 23-42.

Lockett, A. and Thompson, S. (2001), Resource-based view and economics. *Journal of Management* 27 (6): 723-755.

Maskell, P. and A. Malmberg (1999) Localised learning and industrial competitiveness, *Cambridge Journal of Economics*, 25: 167-185.

McKelvey, M., H. Alm & M. Riccaboni (2004) Does location matter? Knowledge collaboration in the Swedish biotechnology-pharmaceutical sector. WP ESSY. Gothenburg: Chalmers University.

OECD (1996) *The Knowledge-based Economy*. Paris: OECD.

Pawlak, Z. (1991), *Rough Sets*, Dordrecht.: Kluwer.

Polkowski, L., Skowron, A. (1998) (eds) *Rough Set in Knowledge Discovery*, Springer, Physica Verlag, Berlin.

Reid, S. and Garnsey, E. (1998), Incubation Policy and Resource Provision: Meeting the Needs of Young Innovative Firms. In: Oakey, R. and Dunning, W. (eds) *New Technology Based Firms in the 1990s*, Volume V, London: Paul Chapman, pp.67-80.

Rosenthal, S.S. and Strange, W.C. (2001), The determinants of agglomeration. *Journal of Urban Economics*, 50: 191-229.

Rutten, R. and F. Boekema (2004) A Knowledge-based view on innovation in regional networks. In: Groot, H.L.F. de, Nijkamp, P. and Stough, R. (eds) *Entrepreneurship and Regional Economic Development. A Spatial Perspective*. Cheltenham: Edward Elgar, pp. 175-197.

Simmie, J. and J. Sennett (1999) Innovative clusters: global or local linkages? *National Institute Economic Review*, 170: 87-98.

Soetanto, D. P., and Geenhuizen, M. van (2005) Technology incubators as nodes in knowledge networks. Proceedings of the 45th Congress of the ERSA, 23-27 August 2005, Amsterdam.

Storper, M. and A. Scott (1995) The wealth of regions: market forces and policy imperatives in local and global context, *Futures*, 27 (5): 505-526.

Teece, D. (2000) Strategies for managing knowledge assets: the role of firm structure and industrial context, *Long Range Planning*, 33 (1); 35-54.

Vohora, A., Wright, M. and A. Lockett (2003) Critical junctures in the development of university high-tech spin-out companies, *Research Policy*, 33 (1): 147-175.

Yin, R.K. (1994) *Case Study Research*. Sage, Thousands Oaks (CA).

Appendix 1. Structure of an information table (two hypothetical examples) a)

Objects b)	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**Decision variable**
	Position	Age	Size	Main activity	Duration innovation projects	General spatial orientation	Spatial layout
O_1	3	2	1	2	1	1	1= Local/ Regional
O_2	1	3	2	1	3	2	2 = Global

a) C_1-C_6: condition variables
b) O_1-O_{21}: companies

Appendix 2. Summary of results of the rough set analysis

	Decision variable: regional/global knowledge networks
Condition variable	**Frequency (in 11 decision rules)**
1.1 Position	5
1.2 Age	3
1.3 Size	3
1.4 Main activity (industry, services)	2
1.5 Duration of innovation projects	3
1.6 General spatial orientation	6
Indicators of strength information table	
Number of *core* variables	5 out of 6
Quality of the *core*	1.0
Indicator of strength of results	
Maximum coverage of rules	41.7%
Coverage of majority of rules (4)	22.2%