Abteilung für Stadt- und Regionalentwicklung
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Franz Tödtling, Patrick Lehner, Michaela Trippl

Knowledge intensive industries, networks, and collective learning

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Franz Tödtling, Patrick Lehner and Michaela Trippl

Vienna University of Economics and Business Administration
Department of City and Regional Development,
Roßauer Lände 23/3, A-1090 Vienna, Austria

e-mail: franz.toedtling@wu-wien.ac.at, patrick.lehner@wu-wien.ac.at,
michaela.trippl@wu-wien.ac.at

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Abstract

Knowledge has become a key source of competitiveness for advanced regions and nations, indicating a transformation of advanced capitalist economies towards "knowledge-based economies". Knowledge intensive sectors in production and in services have a lead in this respect, they can be considered as role models for the future. The innovation process, the mechanisms of knowledge exchange and the respective linkages in those industries differ quite markedly from those in other sectors. Clustering and local knowledge spillovers are frequently stated phenomena, although it is still unclear to what extent regional networks and collective learning are indeed relevant and what the mechanisms of knowledge flows are. The aim of the paper is to examine in a differentiated way the character of the innovation process and the type of interactions in those industries, in order to find out how strongly they are related to regional, national and international innovation systems. We will analyse the relevant types of actors, the respective mechanisms of knowledge exchange and the importance of collective learning and innovation. The paper will discuss relevant theoretical concepts and available evidence and it will be based on an empirical analysis for Austria. The data base is a recent firm survey which was carried out in the year 2003. From this analysis conclusions regarding the role of regional and other innovation systems for the development of knowledge-based industries will be drawn.

1 Introduction

Knowledge has become a key factor of competitiveness for national and regional economies, we are moving towards “knowledge economies“. Knowledge intensive sectors in production and in services have a lead in this respect and to some extent they can be considered as role models for the future. The innovation process, the mechanisms of knowledge exchange and the respective linkages in these industries differ quite markedly from those in other sectors. Clustering and local knowledge spillovers are frequently stated phenomena, although it is still unclear to what extent regional networks and collective learning are indeed relevant and what the mechanisms of knowledge flows are. The intention of the paper is to look more closely at the character of the innovation process and at the types of interaction in knowledge-based industries, in order to find out how strongly they are related to regional, national and international innovation systems. We will analyse the relevant types of actors, the respective mechanisms of knowledge exchange and the importance of collective learning and innovation. The following research questions will be investigated:

- To which extent does the innovation process in knowledge-based sectors differ from other industries?
- Which knowledge sources do firms use and what are the mechanisms and channels of knowledge exchange?
- What is the role of regional knowledge sources and innovation partners in comparison to those at higher spatial levels? To which extent are regional and extra-regional knowledge links substituting or complementing each other?

The paper will discuss relevant theoretical concepts and develop a model of knowledge interactions. Its empirical part contains an analysis for Austria. The data base is a recent firm survey carried out in the year 2003. From this analysis we will draw conclusions regarding the role of regional and other innovation systems for the development of knowledge-based industries.

2 Conceptual background

There is a widespread agreement in the academic literature that innovation, knowledge and learning have become the main source of wealth, employment and economic development in advanced regions and nations. In recent years a considerable body of work has been developed to understand and explain this shift towards a knowledge-based economy (OECD 1996, Dunning 2000, David and Foray 2002, 2003) or a learning economy (Lundvall and Johnson 1994, Lundvall and Borrás 1999, Archibugi and Lundvall 2002). The rise of knowledge intensive sectors in production and in services has to be seen as a main feature of this new area of capitalism.

2.1 Innovation in knowledge-based industries

Innovation processes in knowledge-based industries differ from those in traditional sectors in several aspects. The following questions arise in this context: What are the specific characteristics of the innovation process in those industries and what is the role of codified and tacit knowledge? Which are important actors and institutions and to which extent is there local clustering?

It seems to be increasingly widely accepted that innovation greatly differs across sectors (see amongst others Pavitt 1984 and Malerba 2004). Innovative activities in knowledge-based industries are characterised by several specifics, making them different from those in more traditional sectors. Drawing on the work of Laestadius (1999) and a collective project proposal (TEMPO 2003)[1], Asheim and Gertler (2003) distinguish between analytical and synthetic knowledge bases. The latter one dominates in more traditional industries (like industrial machinery or engineering) and is characterised by the application or novel combination of existing knowledge, low levels of R&D and a strong orientation on solving specific problems articulated by customers. Learning by doing and interacting, practical skills and tacit knowledge are highly important, leading to an incremental innovation pattern in industries with a synthetic knowledge base. In comparison, the innovation process in industries with an analytical knowledge base like biotechnology or information and communication technology is clearly different in nature. There is a strong reliance on scientific inputs and codified (or codifiable) knowledge is in general far more important than in traditional sectors. Knowledge inputs are often based on reviews of existing (codified) studies, knowledge generation is based on the application of widely shared and understood scientific principles and methods, knowledge processes are more formally organised (e.g. in R&D departments) and outcomes tend to be documented in reports, electronic files or patent descriptions. Although the codification of knowledge plays a decisive role in sectors with an analytical knowledge base, tacit knowledge is of relevance, too. The argument put forward here is that there is a complex interplay between codified and tacit knowledge in the process of knowledge creation and innovation (Nonaka and Takeuchi 1995, Lundvall and Borrás 1999, Johnson et al. 2002).

In sectors where an analytical knowledge base prevails there is much more systematic basic and applied research than in traditional industries. The rate of product and process innovations, notably of a radical nature, is high. R&D efforts are typically strongly focussed on generating radical innovations. Academic spin-offs and new firm formation are important mechanisms when it comes to the application and economic exploitation of new analytical knowledge. In knowledge-based industries research is done to a considerable extent within companies. Nevertheless innovating companies are highly dependent on external knowledge sources. Universities, government labs and other research institutions are crucial agents in this respect, providing scientific research inputs for innovating firms. Consequently, various forms of university-industry partnerships (OECD 1998) play a pivotal role in the process of knowledge generation and innovation.

It is often assumed, and there is also some evidence (Feldman and Audretsch 1999, Gehrke and Legler 2001, Carrincazeaux 2002, Cooke 2002), that knowledge-based firms and activities exhibit a strong tendency to concentrate in geographical space. In recent years high-technology clusters, notably in biotechnology and in information and communication technology, have attracted a high research interest (Prevezer 1997, Swann et al. 1998, Baptista and Swann 1999, Bresnahan 2001, Cooke 2002, Fuchs 2003). Spatial clustering, thus, seems to be a striking feature in those sectors.

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[1] Specific Targeted Research Project proposal „Knowledge Production and Innovation through Temporary Organizations“. The consortium consisted of B. Asheim, F. Tödtling, G. Grabher, R. Hassink, M. Gertler, A. Lam, P. Cooke, F. Belussi, A. Mariussen and E. Pedersen.

The industry- or cluster life cycle hypothesis (Swann 1998, Tichy 2001) argues in this context that in particular in the early stages of industry development geographical proximity is vital whereas in latter stages, when the industry matures, economic activities become more geographically dispersed. The importance of tacit knowledge in the innovation process, which is best transmitted via face-to-face contacts and through frequent interaction, is a key factor to explain spatial clustering in knowledge-based sectors, in particular in the early phases (Tödtling 1994). Malmberg and Maskell (2002) noted that co-located firms undertaking similar activities benefit from "observability and comparability advantages", i.e. they can monitor competitors directly and continuously, identify and imitate superior solutions and combine them with their own ideas. Enhanced knowledge creation is the result. Whilst not neglecting that geographical concentration can provide enormous opportunities for the transmission of sticky, non-articulated forms of knowledge between firms ("local buzz"), Bathelt et al. (2002) emphasise the importance of "global pipelines" through which access to codified external knowledge is secured. Indeed, new value can be created by combining these various types of knowledge.

In the above literature, in particular in the cluster approaches, the existence of knowledge spillovers and other relations has been claimed. What is often missing is a more differentiated analysis of these relations, both conceptually and empirically. This will be the focus of the following sections.

2.2 Types of relations and role of the region

The types of relations as well as the role of the region and other spatial levels in the knowledge generation and innovation process have been analysed through different approaches and in a number of studies. Based on this literature we will distinguish in the following between two dimensions, resulting in four main categories of relations. The first dimension refers to Storper´s (1995, 1997) differentiation between traded and untraded interdependencies in the innovation process. Storper argued that it is in particular the untraded, often informal relations which might explain the spatial concentration of innovative industries and activities rather than the traded, more formalised interactions among firms. The second dimension refers to the static versus dynamic aspects of knowledge exchange and innovation interactions. This aspect was discussed e.g. by Capello (1999) and earlier by other authors of the milieu approach (Camagni 1991, Maillat 1998). Static knowledge exchange here refers to the transfer of “ready” pieces of information or knowledge from one actor to the other. Cases would be the licensing of a specific technology, the reading of a patent description of another firm or observation and imitation of other firms. Dynamic knowledge exchange refers to a situation, where there is interactive learning among actors through e.g. cooperation or other joint activities as described by Lundvall (1992), Camagni (1991), Capello (1999) and Lawson (2000). In this case the stock of knowledge is increased through the interaction. This classification provides us with the following four main types of relations (figure 1):

Figure 1: Types of relations in the innovation process

	static (knowledge transfer)	**dynamic (collective learning)**
formal / traded relation	(1) market relations	(3) cooperation / formal networks
informal / untraded relation	(2) knowledge externalities and spillovers	(4) milieu informal networks

It is important to note here that these four types of relations constitute “ideal types” which in real situations can rarely be observed in pure form. Both in the transaction cost (Williamson 1985) and evolutionary economics literature (Hodgson 1988) e.g. it has been pointed out that market relations and networks cannot always be clearly separated, but are positioned rather along a continuum between the ideal types. Also Dosi (1988) and von Hippel (1988) have argued that most relations to suppliers and customers go beyond ideal-type market relations, showing a more durable and interactive nature. Then, there are considerable overlaps between knowledge spillovers and milieu making it difficult to differentiate these categories in real situations. Also the differentiation between milieu and networks has been a matter of debate, since in particular local informal networks are a key element for the development of an innovative milieu (Maillat 1991). We follow here Camagni (1991) who argues that the milieu is characterised rather by informal links and a high degree of tacit knowledge exchange among actors, whereas networks are constituted by formal cooperation connecting the regional milieu with external knowledge sources.

Market relations (1) in the present context refer to the buying of "embodied" technology and knowledge in various forms (Scherer 1992). Traditionally this would be e.g. the buying of machinery, ICT equipment or software, or the buying of licenses. Since the traded technology or knowledge is more or less in a "ready" form, we consider this as a static relation or knowledge transfer. We have to be aware, that in reality there are often more durable and also interactive relations between the buyers and suppliers of machinery and equipment (Gertler 1993) moving this type of relation more towards networks (Dosi 1988). Also "cultural" and institutional influences and barriers of knowledge transfer in the case of new machinery have been observed (Gertler 1993). Nevertheless, we classify these relations as market relations, since, in principle, trade partners could be changed swiftly and the level of interaction is rather low in many cases.

Some studies have shown that there may be some transaction cost and other advantages of regional trade relations in specific cases. Regional user-producer relations may be relevant e.g. for early phases of the product cycle (Tichy 2001), new firms or industrial districts of SMEs (Asheim 1996). A larger number of studies, however, have demonstrated that the traded relations are usually at higher spatial and international levels, reaching clearly beyond the region (Storper 1997, Sternberg 2000). Feldman (2000) considers trade relations as one of the most important mechanisms of interregional and international technology transfer.

There exists meanwhile a considerable body of literature, pointing out that markets are far from perfect with respect to knowledge generation and exchange. A number of authors have demonstrated through econometric methods that there are considerable **local knowledge externalities or spillovers** (2) from universities and research organisations to firms. Jaffe (1989), Audretsch and Feldman (1996), Anselin et al. (1997) and Bottazi and Peri (2002) have investigated and identified such local knowledge spillovers applying a knowledge production function approach. Jaffe et al (1993) have found considerable proximity effects with respect to patent citations. It is argued that local knowledge spillovers result from various kinds of mechanisms such as knowledge exchange e.g. through mobile labour or through face to face contacts (Feldman 2000). In this literature there are also some interesting specifications with respect to knowledge spillovers: Jaffe et al. (1993) demonstrate a time decay of local knowledge spillovers: the most frequent citations of local patents were in the first few years after the patents have been granted. Furthermore, a geographical distance decay of such spillovers was shown by Anselin et al (1997) for the US and by Bottazi and Peri (2002) for Europe.

Networks and milieu are conceptually different from the above categories. They are based often on evolutionary or sociological approaches and the arguments and the reasoning go beyond the transaction cost logic. Compared to market links, **networks** (3) are more durable and interactive relations between specific partners in the innovation process. There is not just an exchange of a given technology or piece of knowledge but a collective further development and an increase of the respective knowledge base. We can speak here of a dynamic process of collective learning (Lundvall and Johnson 1994, Lundvall and Borrás 1999). Innovation networks may take different forms (deBresson and Amesse 1991, Powell and Grodal 2003): some are based on formal agreements or contracts (R&D-cooperation, -collaboration and –alliance, research-consortia) including formal statements on the sharing of tasks, cost, benefits and revenues. These types of networks are often, but not exclusively, including large and international firms, specialised technology companies or major research organisations. Since the search of partners is highly selective and targeted on specific strategic or complementary competences of potential partners, these formal innovation networks are often at an international or even global scale (Archibugi and Iammarino 1999). Hagedoorn (2002) noted that at the end of the 1990s the share of international partnerships was about 50% of all newly made R&D partnerships between firms, whereas high-tech sectors are less internationalised in their R&D partnering. Hagedoorn also has shown that in recent years over 80% of the newly made R&D partnerships are found in information technology and pharmaceutical industries. Innovation networks were investigated in particular for knowledge-based industries such as ICT and biotechnology (Powell et al. 1996, Powell 1998, Godoe 2000, Matuschewski and Zoche 2001, Cooke 2002, Mc Kelvey et al. 2003). These studies have shown that there is also some networking at the regional and national levels, often involving local universities, venture capital and smaller companies (Cooke 2002, Powell et al. 2002). However, more frequently the networks identified in these knowledge-based industries were among international partners. This could be observed in particular for small open economies such as Sweden (McKelvey et al. 2003) or Austria (Schartinger et al. 2000).

Innovation networks may also include more informal links and collaborations among companies and organisations, such as those in industrial districts (Asheim 1996) and in high-tech regions (Saxenian 1994). These are then based on trust, and a shared understanding of problems and objectives, and the acceptance of common rules and behavioural norms. In the literature this is referred to as social capital (Putnam 1993, Wolfe 2000) or a shared culture leading to a specific **innovative milieu** (4) (Camagni 1991, Maillat 1991, 1998, Ratti et al. 1997). The rapid exchange of ideas and knowledge are the key to an innovative milieu, but like in the case of networks there is a dynamic aspect of a collective enhancement of the local knowledge base, i.e. collective learning (Camagni 1991, Capello 1999, Lawson 2000). Collective learning processes in innovative milieus have been investigated for a number of regions in Europe by the GREMI group (Aydalot and Keeble 1988, Camagni 1991, Ratti et al. 1997) as well as more recently by Keeble and Wilkinson (1999, 2000).

Finally, various support organisations and policy actions may promote learning and innovation at the regional level. The concept of regional innovation systems (Autio 1998, Braczyk et al. 1998, Cooke et al. 2000, Doloreux 2002) has led to a better understanding of the role played by the institutional infrastructure in supporting local learning and innovation and it has clarified the policy dimension of such processes. In regions which are well endowed with universities and other research institutions, science parks, innovation centers, technology transfer agencies and educational institutions, the production, diffusion and application of knowledge can be stimulated and enhanced. An important precondition is, however, that these organisations develop dense links to the firms of the regions. Other important organisations supporting innovation-based growth at the regional level include venture capital firms, business angels, standard setting bodies, regional development agencies, local authorities, etc. With respect to political intervention, the regional innovation system concept highlights that regional authorities can shape local learning and innovation processes in a significant way by providing physical capital (R&D- and educational infrastructure), supporting academic spin-offs, enhancing human capital and encouraging the formation of social capital (Nauwelaers 2001, Tödtling and Trippl 2004). Through these activities policy actors try to stimulate various kinds of the above mentioned relationships.

3 Methodology

In the following sections we are going to investigate innovative activities, knowledge sources and types of interactions in Austrian industries, comparing the respective patterns of knowledge intensive sectors with those of more traditional industries. The empirical findings presented below were collected in the context of the research project KNOWING[2].
The KNOWING-project consists of a postal survey of Austrian firms yielding basic insight into the knowledge generation and exchange process and personal interviews with representatives of firms, knowledge institutions as well as policy and support organisations to gain a deeper understanding of the knowledge processes. The postal survey will be discussed in the following sections.

2228 Austrian firms have sampled from the Herold Professional Data base and invited to fill a questionnaire[3]. Approximately two thirds of the firms belonged to the manufacturing sector and one third to the knowledge-intensive service sector (data processing and engineering). 189 firms responded yielding a rate of return around 8,5% (table 1). The sectors have been classified according the OECD classification (OECD 2001) and grouped in four industries: (1) high-tech industry (HT), compromising the NACE sectors Pharmaceuticals (244), ICT (30), Radio, TV and Communication Equipment (32), Medical, Precision and Optical Instruments (33), and Aircraft and Spacecraft (353), (2) knowledge and innovation based services (KIBS) with a focus on Computer and Related Activities (72), Architectural and Engineering Activities and Technical Testing and Analysis (742, 743), (3) research firms (R) with R&D (73), and (4) traditional (medium-tech) manufacturing (MT) compromising the sectors Chemicals without Pharmaceuticals (24 except 244), Machinery (29), and Electrical Machinery and Apparatus (31).

[2] „KNOWING – Collective Learning in Knowledge Economies: Milieu or Market?“ is an ongoing research project (2002-2004) which is financially supported by the Austrian Science Fund (FWF).
[3] The questionnaire was mainly focussed on collecting data on the nature of firms' innovation activities within the last three years, the use of external knowledge sources and their location, the types and mechanisms of knowledge exchange as well as their cooperative behaviour and relationships.

4 Empirical results

4.1 Nature of innovation activities

As to be expected, there are clear differences with respect to internal innovation factors and activities. Partly also for definitional reasons, high-tech (HT) firms and research (R) firms have more continuous research activities (both basic and applied) as well as development activities (table 3). This is also reflected in higher numbers and shares of researchers in total employment and in more patenting activities (table 2). Given the knowledge and innovation orientation of KIBS, it is interesting to observe that they have quite low research activities in comparison with the other sectors. As to be expected, medium-technology (MT) firms also have less basic & applied research and development, but relatively more activities of design and market introduction.

The structure of innovation activities is also reflected in different types of innovation output (table 4): HT and R firms have more innovations "new for the market", whereas MT and KIBS rely more on modifications and technology adoption (innovations "new to the firms") in order to maintain their competitiveness. Innovation strategies, i.e. the attainment of competitive advantages via the introduction of substantial product innovations, thus, have clearly more prominence in the case of HT and R firms, compared to the rest. It is somewhat surprising to find that the KIBS are only slightly more innovation oriented than the MT firms. This may partly have to do with the fact, that the innovation process of service firms is not covered very well by existing innovation concepts. Partly it may reflect the fact that the Austrian KIBS sector for various reasons is less advanced and sophisticated compared to advanced European and US economies (Tödtling and Traxler 1995, European Commission 2002).

There are significant statistical relations between types of activities and types of innovation (table 5): Whereas products "new for the market" correlate significantly with most types of innovation activities including basic and applied research, products "new for the firms" (i.e. technology adoption) correlate only with activities of market introduction and development. Modifications are in an intermediate position and significantly related to development, design and market introduction. More substantial product innovations, thus, imply more complex knowledge and innovation processes including activities of search and exploration, development, design and commercialisation. Modifications rely more on applied and practical forms of knowledge and activities such as development, design and commercialisation, whereas the adoption of new products seems to require less knowledge inputs and activities in comparison.

Innovation processes and activities, thus, clearly differ between the investigated sectors, a fact which has to be taken into account when investigating external knowledge sources and innovation partners.

4.2 Knowledge sources

Also with respect to the dominating sources of knowledge there are clear sectoral differences (table 6). While the most important knowledge sources for the MT firms are other firms along the value chain (customers, suppliers) including competitors, for HT and R firms universities are a clearly more important knowledge source (for 58% and 67% of firms respectively). This finding underlines the importance of not only practical but also scientific knowledge for HT and R firms and demonstrates that these companies rely on a larger variety of knowledge types and respective sources than MT firms. Basically this is in line with other research on knowledge-based industries and related issues (OECD 1996, Keeble and Wilkinson 2000, Asheim and Gertler 2003). For KIBS and R firms, in addition, other service firms and commercial R&D are important knowledge sources. In accordance with results of studies on business services (Daniels 1995, Moulaert and Tödtling 1995) we find, thus, relatively strong knowledge links within the service sector.

Regarding the role of the region we can observe that knowledge sources from the region are clearly more important for all three kinds of knowledge-based sectors in comparison to MT firms (table 7). This is in particular true for universities and service firms, but to some extent also for customers and technology centers. Regarding the reasons for the importance of the region the firms responded that the contacts with knowledge sources from the region are more informal, faster and more appropriate for the respective purpose. Also the ease of contacts and the trustworthiness have been mentioned by more than half of the respondents. A less important reason is a higher security of regional information flows. In general, these results are in line with findings by Kaufmann et al. (2003) on similar questions.

Looking at the spatial levels of knowledge sources in more detail, we find that HT firms are using regional, national and international knowledge sources (table 8). Highly internationalised (EU, US) are in particular knowledge flows from clients, suppliers and competitors, in addition to intra-group knowledge flows. Relevant knowledge sources from the region are universities, technology centers and suppliers, but it is obvious that knowledge sources from the region are in general less important than those from the rest of Austria and from Europe. HT firms thus combine knowledge sources from the region with those of national and international origin in their innovation process. This is in accordance with findings of Cooke et al. (2000), Sternberg (2000) and Bathelt et al. (2002). Basically this pattern holds also true for the other investigated sectors with the qualification that for the KIBS and the R firms the region is a comparatively more important knowledge space. A stronger role of tacit knowledge and a higher need for personal contacts with various knowledge sources and innovation partners might be responsible for this pattern.

There are interesting correlations between the types of innovation activities and the knowledge sources (table 9): Positive correlations, significant at the 1% and 5% levels, are between the performance of basic & applied research and development on the one hand and the use of commercial R&D, universities, non-profit R&D and technology centers as knowledge sources on the other. This can be interpreted both from a demand and capability perspective. On the one hand we can argue that firms performing research and development have a higher need for various kinds of knowledge inputs from these different organisations. On the other hand the performance of these functions enables firms better to interact with and exploit these various knowledge sources.

Significant correlations can also be found between the types of innovation output and the knowledge sources. Only the introduction of innovations "new for the market" correlates strongly with the science- and research related knowledge sources (universities, commercial R&D, non-profit R&D, technology centers). Obviously, the more innovative products not only imply a more complex knowledge process (see above), but they also require inputs from various kinds of knowledge organisations (Kaufmann and Tödtling 2001). Products which are new to the firms only (adoptions) are significantly related just to competitors and service companies as knowledge sources. The relation to competitors could be interpreted as a process of monitoring and imitation of rival companies with respect to new products (Malmberg and Maskell 2002), whereas service companies might contribute knowledge relevant for the introduction and marketing of the new products. Product modifications, in turn, are significantly stimulated by knowledge inputs from clients. This supports the findings of Dosi (1988), von Hippel (1988) and Kaufmann and Tödtling (2001) that in particular smaller changes and improvements of products take place continuously and are strongly stimulated and supported by relations to the clients.

4.3 Knowledge channels and types of interactions

There are not only differences with respect to the knowledge sources, also the transfer mechanisms and channels differ (table 10): For MT firms the most important channels of knowledge exchange are the buying of machinery and software (i.e. market links). Also the places and institutions where trading- and other partners meet (fairs, conferences) as well as informal contacts are important channels. The buying of machinery and software represent a process of embodied technological change cited often in the economic literature of innovation (e.g. Coombs et al. 1987). The participation on fairs and conferences on the other hand can be interpreted in the context of the monitoring of markets and other firms, and of informal knowledge exchange. Like in some other findings shown above, KIBS are quite similar to the MT firms regarding their knowledge channels: fairs & conferences, informal contacts and the hiring of specialists are the dominant mechanisms. In the latter case knowledge is "embodied" in and transferred through mobile qualified labor, an important mechanism of knowledge transfer as pointed out by Saxenian (1994) and Feldman (2000). Both for MT firms and KIBS we find, thus, a mix of market and milieu type of knowledge interactions in the innovation process.

HT firms in addition to intermediate goods and informal contacts rely more on consulting, contract research, R&D cooperation and the joint use of R&D facilities. Since in particular the latter channels are based on more durable and reciprocal relations, we find a stronger overall importance of networks for HT firms. This is in line with many studies on HT industries such as Saxenian (1994), Sternberg (1995), Camagni and Capello (2000) and Bathelt (2001). R firms, finally, get their knowledge through a variety of channels including scientific literature and patents, contract research and research cooperation as well as informal contacts. We can interpret this as a combination of milieu and network type of relations. These firms, thus, have the most distributed knowledge base, drawing on a large variety of knowledge sources and using also a large variety of knowledge channels and interactions.

Which channels for which knowledge sources?

Which channels are used to exploit specific knowledge sources? And what are the differences between high-tech and medium-technology firms in this respect? With respect to **customers** it is not surprising to find, and in line with von Hippel (1988), that fairs and informal contacts are the most important channels of knowledge exchange (table 11). Knowledge from **suppliers** is acquired mainly through the buying of machinery and software, as well as through contacts at fairs and informal contacts. It is interesting to observe, that for MT firms these "traditional" knowledge channels are more important than for HT firms. Also with respect to **competitors** informal contacts and fairs/conferences are the most important channels. Obviously the monitoring of competitors at fairs and conferences including informal talks and knowledge exchange are highly relevant mechanisms for gaining relevant knowledge for own innovations. An additional transfer mechanism is the hiring of specialists which have previously worked for the competitors. This seems to be one of the most effective mechanisms to acquire some of the tacit knowledge of competitors (Saxenian 1994, Henry and Pinch 2000, Malmberg and Maskell 2002). Knowledge from **service companies** is acquired mainly through consulting activities, i.e. in traded form. In particular for MT firms also the buying of software from service companies is relevant. **Commercial R&D firms** are more important for HT firms. The main exchange mechanisms in this case are contract research, R&D cooperation and informal contacts. We find thus a mix of traded and network type of relations. Knowledge from **universities** is accessed more strongly by HT firms, and they use a variety of channels: R&D cooperation and the hiring of specialists are the most important, reading of scientific literature & patents as well as informal contacts follow, contract research, consulting and joint use of R&D facilities are also relevant knowledge channels. For high-tech firms, thus, the knowledge exchange with universities is the most complex: it clearly includes obviously both codified and tacit forms of knowledge as well as market, network and milieu type of relations. For MT firms in comparison the relations to universities are considerable less intensive. The reading of literature & patents is the most frequent, followed by the hiring of specialists and informal contacts.

4.4 Cooperations in the innovation process and their spatial levels

One key mechanisms of knowledge exchange are cooperations. They constitute intentional and selective relations to particular partners in the innovation process and they are more interactive and durable than market links. It is argued in the literature that cooperations are of special importance for technology intensive and knowledge-based sectors because they can reduce uncertainties, provide access to complementary resources and technologies, and speed up the innovation process (Camagni 1991, deBresson and Amesse 1991, Hagedoorn 2002, Fritsch 2003, Fritsch and Franke 2004).

In accordance with this literature we find that firms in knowledge-based sectors cooperate clearly more frequently in the innovation process (49% to 80%) than MT firms (34%). In line with the findings on the use of external knowledge sources we identify the highest shares of cooperating firms among the research firms (80%). But also from the HT firms and KIBS about half of the investigated companies cooperate (table 12).

Regarding the objectives of cooperations we find that for R firms and HT firms the most frequent goals are product innovations "new for the market" and the opening up of new technical fields, i.e. the entering of new technology paths (table 13). Thus, cooperations can be regarded as being a relevant tool for getting access to a complementary knowledge base, distribution channels or other innovation resources.

With respect to the areas of cooperation we can observe that R firms most frequently cooperate in their own core activity, namely basic & applied research and development (table 14). HT firms cooperate most frequently in the medium phases of the knowledge and innovation process: applied research, development and testing are frequent areas of cooperation. KIBS and MT firms cooperate in later phases in comparison: development, testing and commercialisation are their most frequent areas of cooperation. It is obvious, thus, that the cooperations follow more or less the dominant pattern of innovation activities identified above.

Regarding the spatial pattern of cooperations we find a similar pattern to the geography of knowledge sources analysed above: Austria and the European Union are also the most important cooperation spaces, the region also has relevance, but seems to be less important in comparison (table 15). Compared to MT firms, the HT firms are cooperating more both at the level of the region as well as internationally. In particular universities (28%) and commercial R&D (25%) are frequent cooperation partners. R firms had the highest share of cooperative firms. Also for them the region is an important cooperation space in particular for partners from universities (50%) technology centers (50%) and non-profit R&D (42%). But the R firms are even more than the HT firms cooperating also internationally, with the EU and North America as most relevant areas. In particular for HT firms and for R firms, thus, we find a pattern of both regional and international cooperation links in the innovation process. The multilevel character of networks in these sectors is reflected in a higher "network factor"[4] for these types of firms (table 15). Compared to HT and R firms the KIBS cooperate clearly less frequently, and their spatial pattern of cooperation is more confined to the region and the rest of Austria.

5 Conclusions

Our analysis has demonstrated that **knowledge-based sectors innovate** clearly **in a different way** than the more traditional medium-technology sectors. As can be expected, they undertake more often activities of basic & applied research and development and also their innovation output is to a higher extent oriented to more substantial and radical product innovations, including a higher patenting activity. This is in particular the case for HT and R firms, whereas MT firms and KIBS rely relatively more on activities such as development, design and market introduction, focusing in their output more on modifications and technology adoption.

This pattern of innovation activity is also reflected in the predominant **knowledge sources**. Whereas for MT firms the most important knowledge sources are other firms along the value chain (customers, suppliers) including competitors, for HT and R firms universities are a clearly more relevant source. HT and R firms, thus, rely on a larger variety of knowledge inputs including scientific and analytical knowledge than MT firms.

Knowledge sources from the region, in particular universities and service firms, are clearly more important for all three kinds of knowledge-based sectors in comparison to MT firms. However, it is obvious that HT firms rely even more on international knowledge sources than on regional ones. Highly internationalised are in particular knowledge flows from clients, suppliers and competitors, in addition to intra-group knowledge flows. HT firms thus combine

[4] The network factor indicates the number of spatial levels of cooperations with a specific type of partner. For example if the firms that cooperate with a supplier identify the supplier only on one spatial level the network factor is 1 compared with the maximum network factor of 6 when cooperating with suppliers on all 6 spatial levels.

knowledge sources from the region with those of national and international origin in their innovation process.

There are **significant statistical relations** between internal innovation activities (basic & applied research, development), specific external knowledge sources and the kind of innovation output. Innovations new for the market correlate positively with basic and applied R&D, and with the use of specific knowledge sources such as commercial R&D, universities, non profit R&D and technology centers. More fundamental innovations, thus, rely on a larger variety of knowledge inputs both from inside the firms and from outside. On the other hand, the adoption of new products seems to be more related to the monitoring of competitors and specific inputs from service firms.

There are not only differences with respect to the knowledge sources, also the **transfer mechanisms and channels** differ: For MT firms and KIBS the most important channels of knowledge exchange are the buying of equipment and software (i.e. market links), fairs, informal contacts and the hiring of specialists. “Embodied” knowledge flows (both in persons and equipment), the monitoring of markets and other firms (fairs), and informal knowledge exchange are dominating. Both for MT firms and KIBS we find, thus, a mix of market and milieu type of knowledge interactions in the innovation process.

HT firms in comparison rely more on consulting, contract research, R&D cooperations and the joint use of R&D facilities. More durable, interactive and reciprocal relations, and thus networks, have more importance for this type of firms. R firms use the largest variety of channels to access external knowledge sources including scientific literature & patents, contract research and research cooperations as well as informal contacts. We can interpret this as a combination of market, network and milieu type of relations. These firms, thus, have the most distributed knowledge base, drawing on a large variety of knowledge sources and using also a large variety of knowledge channels and interactions.

HT firms and R firms not only cooperate more often than MT firms and KIBS, also the **goals and areas of cooperation** differ. More fundamental product innovations and the opening up of new technical fields, and thus strategic goals, are of particular importance. The areas of cooperation follow the dominant pattern of innovation activities identified. R firms cooperate most frequently in their own core activity, namely basic & applied research and development, whereas HT firms cooperate more in the medium phases such as applied research, development and testing. KIBS and MT firms focus in their cooperation relatively more on later phases such as development, testing and commercialisation.

These empirical results indicate that the innovation process in knowledge-based industries is a complex phenomenon. Understanding these processes requires a differentiated analysis of knowledge interactions. As shown in this paper there are different sources of external knowledge as well as various types of relationships (market, spill-overs, network and milieu). It has also become clear from our analysis that innovation interactions between actors of knowledge generation and exploitation have a multi-level character and take place at regional, national and international levels. Regional, national and international innovation systems, thus, overlap and play a central and complementary role for the development of knowledge-based sectors in Austria. To neglect one of these spatial levels in the analysis would mean to overlook major linkages in knowledge economies.

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Tables:

Table 1 - Sample for Postal Survey

Sectors (Nace 1995 Rev.1)	Sample	Return	Rate of Return
Medium-technology (24, 29, 31)	816	62	0,0760
High-tech-technology (244, 30, 32, 33, 353)	593	56	0,0944
KIBS (72, 742, 743)	675	51	0,0756
Research (73)	144	16	0,1111
Not Classified		4	
Total	**2228**	**189**	**0,0848**

Firm Size

Employees > 10; 244, 353 and 73 without size restrictions

Table 2 - Firm Economic and Innovation Data

	Medium-tech	High-tech	KIBS	Research	Total
Employment 02	147	93	54	74	98
Turnover 02 (Mio Euro)	25,07	16,84	9,01	4,84	16,59
Export Ratio 02 (%)	46,34	44,04	16,95	34,15	37,26
R&D Ratio 02 (%)	4,18	31,27	7,36	62,93	19,76
R&D Department (%)	40	66	31	67	48
Researchers (%)	21	50	9	93	33
Number of Researchers	4	14	39	32	19
Technicians (%)	97	91	100	86	95
Number of Technicians	30	38	35	10	32
Patents (%)	39	57	8	47	36
Number of Patents	5	3	10	4	4

(averages and in %)

Table 3 - Innovation Activities

	Medium-tech	High-tech	KIBS	Research
Basic Research (%)				
Yes, regularly	14,5	20,0	17,8	66,0
Occasionally	12,7	26,0	20,0	26,7
No	72,7	54,0	62,2	6,7
Applied Research (%)				
Yes, regularly	16,1	48,1	13,6	100,0
Occasionally	26,8	19,2	40,9	0,0
No	57,0	32,7	45,0	0,0
Development (%)				
Yes, regularly	60,7	72,7	55,3	93,3
Occasionally	21,3	10,9	29,8	6,7
No	18,0	16,4	14,9	0,0
Design (%)				
Yes, regularly	66,7	58,5	37,8	7,1
Occassionally	18,3	7,5	31,1	57,1
No	15,0	34,0	31,1	35,7
Market Implementation (%)				
Yes, regularly	47,5	67,3	44,0	20,0
Occassionally	34,4	20,0	40,0	73,3
No	18,0	12,7	16,0	6,7

Table 4 - Type of Innovation (%)

	Medium-tech	High-tech	KIBS	Research
Improvement of existing product	87,7	88,4	93,0	93,3
Innovation, new to the firm	70,2	65,1	69,8	66,7
Innovation, new to the market	60,0	77,6	66,7	92,3

Table 5 - Correlation between Innovation Activity and Type of Innovation (all sectors)

	Basic Research	Applied Research	Development	Design	Implementation	Improvement	Firm Innovation	Market Innovation
Basic Research		**0,544**	**0,310**	*ns*	0,195	*ns*	*ns*	**0,355**
Applied Research	**0,544**		**0,282**	*ns*	0,191	*ns*	*ns*	**0,277**
Development	**0,310**	**0,282**		**0,380**	**0,424**	**0,262**	0,164	**0,286**
Design	*ns*	*ns*	**0,380**		**0,388**	**0,227**	*ns*	*ns*
Market Implementation	0,195	0,191	**0,424**	**0,388**		**0,425**	**0,189**	**0,289**
Improvement	*ns*	*ns*	**0,262**	**0,227**	**0,425**		**0,263**	*ns*
Firm Innovation	*ns*	*ns*	0,164	*ns*	**0,189**	**0,263**		*ns*
Market Innovation	**0,355**	**0,277**	**0,286**	*ns*	**0,289**	*ns*	*ns*	

significant 1% level
significant 5% level
ns not significant

Table 6 - Importance* of Knowledge Sources (%)

	Medium-tech	High-tech	KIBS	Research
Own Firm	96,7	100,0	95,8	100,0
Group	56,1	54,0	37,2	50,0
Customer	83,1	80,8	85,1	73,3
Supplier	79,7	51,9	58,3	46,7
Competitor	56,7	50,0	53,2	66,6
Service Firm	28,3	25,0	43,2	40,0
Commercial R&D	20,7	33,4	37,8	40,0
University	29,3	57,7	32,6	66,7
Non-Profit R&D	13,8	11,8	10,9	26,7
Technology Transfer Center	13,8	17,6	20,0	40,0

% of firms, rating knowledge source as important or very important

Table 7 - Regional Importance* of Knowledge Sources (%)

	Medium-tech	High-tech	KIBS	Research
Group	22,2	20,5	18,0	9,1
Customer	42,3	45,1	60,9	57,2
Supplier	42,4	26,5	35,5	35,7
Competitor	15,8	22,0	21,8	7,1
Service Firm	29,6	43,8	39,6	35,7
Commercial R&D	20,0	32,6	24,4	35,7
University	38,1	65,4	56,8	78,5
Non-Profit R&D	25,9	17,7	16,7	71,5
Technology Transfer Center	27,8	23,4	37,2	57,1

% of firms, rating the regional existence of the knowledge source as important or very important

Table 8 - Geographical Location* of Knowledge Sources (%)

High-tech	Region	Austria	EU	USA, CDN	Asia	Rest
Group	8,9	14,3	41,1	25,0	1,8	3,6
Customer	16,1	44,6	51,8	26,8	19,6	8,9
Supplier	17,9	44,6	57,1	23,2	5,4	3,6
Competitor	8,9	21,4	48,2	39,3	10,7	3,6
Service Firm	14,3	41,1	26,8	7,1	0,0	0,0
Commercial R&D	10,7	37,5	25,0	10,7	1,8	0,0
University	21,4	53,6	39,3	14,3	1,8	0,0
Non-Profit R&D	14,3	21,4	19,6	7,1	1,8	0,0
Technology Transfer Center	17,9	35,7	12,5	3,6	0,0	0,0

% of firms, using a knowledge source at the relevant geographical level

Table 9 - Importance* of Knowledge Sources and Innovation Characteristics

	Basic Research	Applied Research	Development	Design	Implementation	Improvement	Firm Innovation	Market Innovation
Own Firm	+++	++	+++					++
Group								
Customer			++	+	++	+++		++
Supplier	---							
Competitor							++	
Service Firm	++		+				++	+
Commercial R&D	+++	+++	+++		++			+++
University	+++	+++	+++	+	+++	++		+++
Non-Profit R&D	+++	++	++		++			+++
Technology Transfer Center	+++	++	++	+++	++			+++

* Mann-Whitney U-Test

Knowledge source more (less) important, significant 1% level +++ (---)

Knowledge source more (less) important, significant 5% level ++ (--)

Knowledge source more (less) important, significant 10% level + (-)

Table 10 - Knowledge Transfer Channels (%)

	Medium-tech	High-tech	KIBS	Research
Employment	58,1	60,7	68,6	68,8
Intermediate Goods	79,0	66,1	66,7	68,8
Literature, Patents	66,1	67,9	60,8	75,0
Conferences, Fairs	74,2	66,1	72,5	62,5
Informal Contacts	79,0	71,4	74,5	81,3
Licenses	27,4	39,3	23,5	56,3
Consulting	59,7	62,5	52,9	75,0
Contract Research	37,1	51,8	33,3	75,0
Research Cooperation	40,3	60,7	35,3	75,0
Shared Use of R&D Facilities	33,9	50,0	19,6	75,0
Firm Take Over	29,0	19,6	15,7	12,5

Table 11 - Knowledge Transfer Channels and Types of Sources (%)

Medium-tech	Customer	Supplier	Competitor	Service	Commercial R&D	University	Non-Profit R&D
Employment	12,9	19,4	27,4	14,5	3,2	19,4	1,6
Intermediate Goods	4,8	66,1	3,2	32,3	1,6	1,6	1,6
Literature, Patents	16,1	21,0	16,1	17,7	12,9	25,8	9,7
Conferences, Fairs	37,1	43,5	24,2	14,5	8,1	9,7	4,8
Informal Contacts	58,1	61,3	32,3	14,5	14,5	19,4	9,7
Licenses	4,8	9,7	12,9	6,5	1,6	3,2	1,6
Consulting	1,6	9,7	0,0	40,3	11,3	12,9	3,2
Contract Research	6,5	4,8	0,0	9,7	9,7	17,7	4,8
Research Cooperation	11,3	9,7	3,2	8,1	6,5	16,1	4,8
Shared Use of R&D Facilities	4,8	8,1	0,0	3,2	8,1	9,7	4,8
Firm Take Over	4,8	6,5	12,9	4,8	0,0	0,0	1,8
High-tech							
Employment	7,1	7,1	23,2	14,3	8,9	39,3	5,4
Intermediate Goods	1,8	51,8	7,1	12,5	5,4	7,1	0,0
Literature, Patents	12,5	16,1	19,6	12,5	8,9	33,9	10,7
Conferences, Fairs	32,1	44,6	33,9	12,5	10,7	16,1	7,1
Informal Contacts	42,9	33,9	35,7	23,2	16,1	32,1	16,1
Licenses	3,6	7,1	14,3	7,1	3,6	5,4	3,6
Consulting	1,8	10,7	5,9	42,9	16,1	17,9	1,8
Contract Research	8,9	8,9	0,0	8,9	21,4	19,6	3,6
Research Cooperation	12,5	17,9	16,1	5,4	17,9	41,1	8,9
Shared Use of R&D Facilities	5,4	7,1	7,1	3,6	10,7	25,0	5,4
Firm Take Over	1,8	8,9	7,1	5,4	1,8	0,0	1,8

Table 12 - R&D Cooperation (%)

Industry	%
Medium-tech	33,9
High-tech	49,0
KIBS	48,9
Research	80,0
Total	**46,5**

Table 13 - Objective of R&D Cooperation (%)

	Medium-tech	High-tech	KIBS	Research
Improvement of existing product	77,8	81,8	84,2	90,0
Innovation, new to the firm	66,7	68,2	70,6	30,0
Innovation, new to the market	78,9	95,8	84,2	100,0
Patent development	55,6	50,0	13,3	55,6
Entering new technical fields	68,4	87,5	76,5	100,0
Joint publication	47,1	40,9	43,8	80,0

Table 14 - Area of R&D Cooperation (%)

	Medium-tech	High-tech	KIBS	Research
Basic Research	25,0	47,6	29,4	100,0
Applied Research	52,9	83,3	33,3	100,0
Development	95,0	83,3	95,2	90,0
Prototyping, Testing	88,9	82,6	78,9	70,0
Commercialization	43,8	31,8	58,8	77,8

Table 15 - Geographical Pattern of R&D Cooperation (%)

Medium-tech	Region	Austria	EU	USA, CDN	Asia	Rest	NWF
Group	10,0	10,0	35,0	10,0	5,0	10,0	1,60
Customer	15,0	30,0	40,0	10,0	5,0	5,0	1,91
Supplier	20,0	25,0	45,0	5,0	0,0	0,0	1,58
Competitor	0,0	5,0	20,0	5,0	0,0	5,0	1,40
Service Firm	20,0	25,0	10,0	0,0	0,0	0,0	1,57
Commercial R&D	5,0	35,0	20,0	5,0	0,0	5,0	1,40
University	20,0	55,0	10,0	5,0	5,0	5,0	1,43
Non-Profit R&D	5,0	10,0	10,0	0,0	0,0	0,0	1,00
Technology Transfer Center	5,0	10,0	10,0	0,0	0,0	0,0	1,00

High-tech	Region	Austria	EU	USA, CDN	Asia	Rest	NWF
Group	4,0	8,0	28,0	16,0	4,0	4,0	1,78
Customer	16,0	24,0	44,0	20,0	8,0	0,0	2,00
Supplier	12,0	36,0	48,0	20,0	12,0	0,0	1,88
Competitor	4,0	16,0	28,0	12,0	4,0	0,0	1,60
Service Firm	16,0	48,0	32,0	4,0	0,0	0,0	1,56
Commercial R&D	24,0	32,0	28,0	4,0	0,0	0,0	1,47
University	28,0	60,0	52,0	12,0	0,0	0,0	1,81
Non-Profit R&D	8,0	16,0	4,0	0,0	0,0	0,0	1,40
Technology Transfer Center	8,0	16,0	8,0	0,0	0,0	0,0	1,00

KIBS	Region	Austria	EU	USA, CDN	Asia	Rest	NWF
Group	13,0	21,7	8,7	0,0	0,0	0,0	1,25
Customer	26,1	56,5	21,7	0,0	0,0	4,3	1,56
Supplier	13,0	34,8	17,4	0,0	0,0	0,0	1,36
Competitor	13,0	30,4	21,7	0,0	0,0	0,0	1,25
Service Firm	26,1	34,8	8,7	0,0	0,0	0,0	1,23
Commercial R&D	4,3	8,7	4,3	0,0	0,0	0,0	1,00
University	21,7	21,7	13,0	4,3	4,3	0,0	1,25
Non-Profit R&D	8,7	8,7	4,3	0,0	0,0	0,0	1,00
Technology Transfer Center	17,4	8,7	4,3	0,0	0,0	0,0	1,16

Research	Region	Austria	EU	USA, CDN	Asia	Rest	NWF
Group	16,7	16,7	16,7	0,0	0,0	0,0	1,50
Customer	41,7	50,0	50,0	25,0	0,0	16,7	2,75
Supplier	25,0	33,3	33,3	16,7	0,0	0,0	1,86
Competitor	25,0	41,7	58,3	8,3	0,0	8,3	2,43
Service Firm	25,0	33,3	16,7	8,3	0,0	8,3	2,20
Commercial R&D	33,3	41,7	25,0	0,0	0,0	8,3	1,86
University	41,7	75,0	58,3	33,3	16,7	25,0	3,33
Non-Profit R&D	50,0	66,7	41,7	8,3	0,0	16,7	2,45
Technology Transfer Center	50,0	58,3	8,3	0,0	0,0	0,0	1,55

NWF= Network Factor

SRE

Abteilung für Stadt- und Regionalentwicklung
Wirtschaftsuniversität Wien
Abteilungsleiter: o.Univ.Prof. Edward M. Bergman, PhD

Roßauer Lände 23/3
A-1090 Wien, Austria

Tel.: +43-1-31336/4777 Fax: +43-1-31336/705 E-Mail: sre@wu-wien.ac.at
http://www.wu-wien.ac.at/inst/sre