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Do different types of innovation rely on specific kinds of knowledge interactions?

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Abstract

It is commonly accepted nowadays that innovations are brought forward in an interactive process of knowledge generation and application. The business sector, the science sector, and policy actors are involved in this process as has been stressed in concepts such as innovation systems and the network approach. It is still unclear, however, as to what extent different kinds of innovation rely on specific knowledge sources and links. More advanced innovations on the one hand might draw more on scientific knowledge, generated in universities and research organizations. Such knowledge is often exchanged in personal interactions at a local or regional level. Incremental innovations and the adoption of new technologies, on the other hand, seem to occur often in interaction with partners from the business sector also at higher spatial levels. In this paper, we analyze such patterns of knowledge links. After dealing with knowledge interactions from a conceptual view and reviewing the relevant literature, we present an empirical analysis for Austria. The findings show that firms introducing more advanced innovations are relying to a higher extent on R&D and patents, and that they are cooperating more often with universities and research organizations. Firms having introduced less advanced innovations rely more on knowledge links with business services. Furthermore, the employment of researchers was identified as a key factor enhancing knowledge interactions of firms with universities.

Keywords: Innovation; Cooperation; Network; Innovation system; Knowledge interaction; University–firm links; Location

1. Introduction

Innovations are to an increasing extent seen as the result of an interactive process of knowledge generation, diffusion and application. The importance of knowledge interactions for innovation has been stressed by the literature on innovative milieux (Camagni, 1991), knowledge spillovers (Bottazzi and Peri, 2003), innovation networks (Powell and Grodal, 2005), and innovation systems (Edquist, 2005). According to the innovation systems model, the business sector, the science sector, and policy actors are involved in this process. What is often neglected in the literature is the aspect as to what extent different kinds of innovation rely on specific knowledge sources and links. Advanced or radical innovations are said to draw on new scientific knowledge, generated in universities and research organizations. It is often assumed that the exchange of this type of knowledge requires intensive personal interactions, favoring local and regional levels over others. Incremental innovations on the other hand are said to take place more in interaction with partners from the business sector often located at higher spatial levels beyond the region. Such a pattern might be too simple, however, since there is often a more complex interplay of different types of knowledge and of knowledge sources involved (Bathelt et al., 2004).

In the present paper, we will analyze, thus, the relationship between innovation and external knowledge links of companies. More specifically we will investigate which types of innovation are related to particular kinds of knowledge links—characterized by the kind of innovation partners and the mode of knowledge exchange, i.e. whether these are formal market transactions, networks, or

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informal spillovers and milieu effects. Since universities are regarded as key knowledge sources of firms for more advanced innovations, we investigate in a second step the factors influencing knowledge links between firms and universities.

In the following section, we will deal conceptually with the interactive innovation approach and the types of knowledge interactions involved. In Section 3, we present a literature survey regarding empirical evidence on the role of knowledge links, in particular of cooperations, for innovation. In Section 4, then, it will be investigated empirically for Austria which company characteristics and kinds of innovation partners influence their innovation output. This analysis is based on a telephone survey of Austrian firms and it applies a modified knowledge production function model. Section 5, finally, is focusing specifically on the knowledge links of firms with universities and analyzes which factors have an influence on this particular kind of relation. Section 6 summarizes the major findings and draws some policy conclusions.

2. Innovation and knowledge interactions—conceptual background

The suggestion that innovation is an interactive process is nowadays broadly accepted. In fact, a number of approaches and concepts such as the following have supported this argument:

- The innovative milieux approach (Aydalot and Keeble, 1988; Camagni, 1991; Maillat, 1998),
- Innovation system concepts in different variants: national (NIS: Lundvall, 1992; Nelson, 1993; Edquist, 1997, 2005), sectoral and technological (SIS: Breschi and Malerba, 1997; Malerba, 2005), and regional innovation systems (RIS: Cooke et al., 2000, 2004; Doloreux, 2002; Asheim and Gertler, 2005),
- Innovation networks and related works (De Bresson and Amesse, 1991; Cooke and Morgan, 1998; Powell, 1998; Hagedoorn, 2002; Fritsch, 2003; Quimet et al., 2004; Grodal, 2004; Powell and Grodal, 2005; Hagedoorn et al., 2005; Giuliani, 2007; Nieto and Santamaria, 2007; Katzy and Crowston, 2008),
- Studies on clusters and knowledge spillovers (Audretsch and Feldman, 1996; Baptista and Swann, 1998; Feldman, 2000; Keeble and Wilkinson, 2000; Malmberg and Maskell, 2002; Beaudry and Breschi, 2003).

Although these approaches share the interactive view of innovation (Kline and Rosenberg, 1986), they differ with regard to the conceptualization of the specific actors, key factors and relations seen to be central for innovation:

- The studies on innovative milieux have stressed the importance of informal relationships among local firms and protagonists, and soft factors such as a common understanding and behavioral attitudes for starting and maintaining innovation processes in a region.
- The innovation systems literature argues that the institutions relevant for a specific sector (SIS), a country (NIS) or a region (RIS) have an influence on innovation. Of key importance are the regulatory context (such as intellectual property rights, technical standards), organizations for knowledge generation and diffusion (universities, education, technology transfer) as well as firms willing and capable to commercialize such knowledge.
- The network approach looks at specific, well-selected relationships in the innovation process among specific actors both in the region and beyond. It stresses motives for engaging in cooperations such as technological complementarities or access to resources and specific knowledge, and it emphasizes the role of trust and social capital for the development of networks.
- The studies on clusters and knowledge spillovers finally argue that the spatial concentration of firms and supporting organizations in specific industries may give rise to knowledge spillovers and enhanced innovation. In this type of approach, the knowledge flow is regarded as an externality, where the mechanisms of knowledge transmission often remain unclear. These may be the monitoring and imitation of competitors (Malmberg and Maskell, 2002), the reading of patents or scientific articles (Jaffe et al., 1993), the setting up of spin-offs or the mobility of qualified labor (Keeble and Wilkinson, 2000).

Of particular relevance for our questions are the innovation systems approach and the studies on innovation networks, since they are more explicit on the kinds of knowledge sources and types of interactions and links involved in the innovation process. The sectoral innovation systems approach (SIS: Breschi and Malerba, 1997; Malerba, 2005) has focused on the key actors (firms and organizations), regulations and institutions relevant for innovation in a particular sector or technology. Sectoral innovation systems and related networks are not confined to particular territories, often they have an international or even global reach. In territorial innovation systems (NIS and RIS), the role of national and regional institutions is pointed out and the relationships among the different actors are conceived as being socially and territorially embedded (Granovetter, 1973; Asheim and Gertler, 2005). The NIS approach (Lundvall, 1992; Nelson, 1993) emphasizes the institutional particularities of countries as relevant for innovation and has put the nation as the appropriate territorial unit into the center. However, advanced by the tacit knowledge debate, there has recently been a shift in the spatial focus from the national to the regional level. The creation of new knowledge is characterized by the interaction of codified and tacit knowledge (Nonaka and Takeuchi, 1995). Personal interactions in a common institutional context facilitate the transfer of tacit knowledge (Asheim and Gertler, 2005; Boschma, 2005). Since personal interactions are sensitive to increasing distance (David and Foray, 2003), it is argued that spatial proximity favors knowledge exchange, knowledge spillovers and innovation relationships. As a consequence, the focus of research partially has shifted from national to regional systems of innovation (Cooke et al., 2000, 2004) and to local industry clusters (Baptista and Swann, 1998; Keeble and Wilkinson, 2000; Malmberg and Maskell, 2002).

In the above-mentioned literature on interactive innovation (milieu, innovation systems, networks, clusters), a large variety of knowledge links is mentioned, but there is little clarity on the involved types of knowledge relations. In a recent paper (Tödtling et al., 2006), we have classified knowledge relations along two dimensions. Relying on Storper (1997) we have differentiated between traded (formal) and untraded (informal) relations, and following Capello (1999), we have distinguished between static and dynamic knowledge interactions. Regarding the first dimension, Storper has 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 formalized interactions among firms. Regarding the second dimension, static knowledge exchange implies a transfer of ''ready'' pieces of information or knowledge from one actor to the other, such as the licensing of a specific technology or the interpretation of a patent description. Dynamic knowledge exchange refers to a situation where interactive learning takes place among actors through cooperation or other joint activities as described by Camagni (1991) and Lawson (2000). In this case, the stock of knowledge is increased through the interaction. This classification leads to the following four main types of relations (Fig. 1). They constitute ''ideal types'' which in reality can be rarely observed in pure form.

Market relations (1) refer to the buying of ''embodied'' technology and knowledge in various forms such as the buying of machinery, ICT equipment or software, or the buying of licenses. Since technology or knowledge is traded more or less in a ''ready'' form, we consider this as a static relation or knowledge transfer. A number of studies have demonstrated that the traded relations are usually at higher spatial levels, reaching clearly beyond the region (Storper, 1997; Sternberg, 2000). Feldman (2000) considers trade links as one of the most important mechanisms of interregional and international technology transfer. Markets, however, are far from perfect with respect to knowledge generation and exchange. A number of studies have demonstrated through econometric methods that there are considerable *local knowledge externalities or spillovers* (2), in particular from universities and research organizations to firms. Different from market links there is no contract or formal compensation for the acquired knowledge. Audretsch and Feldman (1996), Anselin et al. (1997) and Bottazzi and Peri (2003) 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 through mobile labor or through informal contacts (Feldman, 2000).

	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

Fig. 1. Types of knowledge interactions in the innovation process.

Networks and milieux are conceptually different from the above categories. They are based on evolutionary or sociological approaches and the reasoning goes beyond the transaction cost logic. Compared to market links, *networks* (3) are more durable and interactive relations between specific partners in the innovation process. A given technology or piece of knowledge is not only exchanged but collectively further developed and the respective knowledge base increased. This constitutes a dynamic process of collective learning (Lundvall and Johnson, 1994; Lundvall and Borrás, 1999; Katzy and Crowston, 2008). Innovation networks may take different forms (De Bresson and Amesse, 1991; Powell and Grodal, 2005): some are based on formal agreements or contracts (R&D-cooperations, R&D-alliances, 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, specialized technology companies or major research organizations. 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. They are most frequent in knowledge-based industries such as ICT and biotechnology (Powell, 1998; Hagedoorn, 2002; McKelvey et al., 2003).

Innovation networks may also include more *informal links* among companies and organizations, such as those in industrial districts (Asheim, 1996) and in high-tech regions (Saxenian, 1994). Such relations are particularly based on trust, a shared understanding of problems and objectives, and the acceptance of common rules and behavioral norms. In the literature, this is referred to as social capital (Putnam, 1993; Wolfe, 2002) or a shared culture leading to a specific *innovative milieu* (4) (Camagni, 1991; Maillat, 1998; Ratti et al., 1997). The rapid exchange of ideas and knowledge is the key to an innovative milieu, but as in the case of networks, there is a dynamic aspect of a collective enhancement of the local knowledge base through continuous innovation interactions, i.e. collective learning (Lawson, 2000).

Besides different types of relationships, we find different kinds of partners involved in the innovation process. Von Hippel (1988) and Porter (1998) have stressed the role of demanding customers for bringing forward new solutions and products. Several authors see an even stronger active role and participation of customers in the innovation process through the application of toolkits for user innovation and design (Von Hippel and Katz, 2002; Franke and Schreier, 2002) or through a virtual integration of customers into the company's innovation process (Füller and Matzler, 2007). In addition to the role of customers, Amara and Landry (2005) and Nieto and Santamaria (2007) emphasize the role of key suppliers for bringing forward product innovations. Porter (1998) as well as Malmberg and Maskell (2002), furthermore, argue that in particular competitors in local industry clusters often stimulate innovations. According to the latter authors, the monitoring of competitors seems to be a more relevant mechanism for knowledge transfer and innovation than input–output links or cooperation. Finally, knowledge providers such as universities and research organizations have been identified as key knowledge sources for innovating firms, in particular in studies of high-tech industries (Saxenian, 1994; Powell, 1998; Keeble and Wilkinson, 2000). Although there were considerable barriers of knowledge transfer to industry in the past (Kaufmann and Tödtling, 2001), universities and research organizations have taken on a more active role in transferring their knowledge to companies more recently (Bozeman, 2000; Fritsch, 2001; Vuola and Hameri, 2006).

We will take up this classification of knowledge links and innovation partners in the literature survey of Section 3 as well as in the empirical study for Austria presented below. In Section 4 we will analyze which types of partners (customers, suppliers, business services, universities and research organizations) have an impact on specific kinds of innovation (Section 4). In Section 5 we focus specifically on the innovation links of companies to universities investigating the factors leading to contract research (market type), joint research (cooperation/network type) and informal knowledge exchange (spillover or milieu type).

3. Knowledge links and innovation: findings from the literature

Innovations, thus, are occurring within a complex web of formal and informal as well as static and dynamic relationships. Looking at empirical evidence, we find on the one hand studies on knowledge spillovers from universities and research organizations as, e.g. by Jaffe et al. (1993), Audretsch and Feldman (1996), Baptista and Swann (1998), and Bottazzi and Peri (2003). These approaches often use a knowledge production function approach, estimating potential effects of research activities on innovation performance of regional firms in an indirect way. The concrete links between universities or research organizations and firms are usually not explicitly investigated, however. The milieu approach on the other hand is often based on qualitative research methods (Ratti et al., 1997; Maillat, 1998) where it is hard to investigate knowledge linkages and their effects in a comparative and more representative way.

In the following, we focus therefore mainly on the role of—mostly formal—networks for innovation, since they can more easily be identified and analyzed in statistical analyses. Most studies on this topic have been dealing with innovation cooperations, i.e. dyadic relationships between firms and their partners in the innovation process. More recently we find also contributions focusing on the network configuration and the respective position of firms in such wider networks.

What is the evidence regarding the relationship between networking (cooperation) and innovation so far? Although there is already a substantial empirical literature on this topic, the direction of the causal relationship is not clear (Fritsch, 2001). Some authors argue that the division of labor in the innovation process leads to or requires more networking. Innovative companies need complementary knowledge (both codified and tacit) which cannot be readily acquired on spot markets but rather through more durable relationships such as cooperations. Other authors observe the reverse direction of such relationships, i.e. that cooperation (networks) stimulates innovation. This suggests that there is no clear causal relationship between networking and innovation, but that it is an interrelated process, occurring in time and space.

Fritsch (2001), summarizing some of the relevant literature, found that "… our understanding of the importance of cooperation and spatial proximity for the division of innovative labor and the efficiency and quality of regional innovation systems is still rather vague. Little is known, e.g. about the role of certain types of actors (e.g. academic institutions) or types of relationships for regional innovation systems. In particular, it is unclear how far interregional differences in cooperative behavior exists and if there is a causal relationship between the propensity to cooperate on R&D and the output of innovation activities". Fritsch (2001) investigated empirically the propensity to engage in cooperation and found out that this is positively influenced by firm size and R&D-intensity. The strongest positive influence of size and R&D-intensity were found for cooperations with public research institutions. In addition, location and sector were significant variables influencing the propensity to cooperate. He also investigated the importance of spatial proximity for cooperative relationships and found that proximity is most important for cooperation with public research institutions.

The propensity to cooperate has also been investigated by Angel (2002) for the chemical, electronics and instruments industries in the US. The author has focused on technology development partnerships with other companies (suppliers, customers, other firms) and found that large firms and those in major urban areas are more likely to enter into technology partnerships. Firms located in technologically specialized agglomerations did not demonstrate a higher propensity of entering such technology development partnerships, however.

Dachs et al. (2004) have analyzed the propensity to cooperate in the innovation process for Austrian and Finnish firms using data from the European community innovation survey (CIS 3). The study finds that the rate of innovators is quite similar in Austria and Finland but that Austrian firms cooperate less than their Finnish counterparts. The gap regarding cooperating firms was particularly large for the segment of small firms (below 250 employees) and in low-tech industries. Applying a multiple regression model, they find that the factors influencing cooperative behavior in the innovation process differ between Austria and Finland, reflecting differences of the respective national innovation systems. In the case of Austrian firms, cooperative behavior was influenced by sectoral affiliation (a positive influence of medium-low-tech sectors such as plastic products, basic metals and fabricated metal products), R&D-expenses and EU-funding. The sectors mentioned are those where Austrian firms are indeed quite competitive. R&D-expenses seem to be a precondition for cooperation, whereas EU-funding might reflect a positive influence of EU framework programs.

Fritsch and Franke (2004), then, have investigated as to what extent innovation output (patenting activity, number of patents) is influenced by R&D-expenses, spillovers (measured by R&D in other firms in the same industry, in business-related services or in public research), cooperation, and by location. By looking at patents, the authors focus on more advanced innovations beyond incremental change. They have applied a Logit model for the dichotomous dependent variable "registration of a patent in the last 3 years" and a negative-binomial (negbin) regression for the dependent variable "number of innovations registered for patenting". Responses of 1800 firms from the regions of Baden, Hannover, and Sachsen were analyzed. The results show a significant positive influence of R&D-expenditure as well as significant positive effects of regional spillovers, in particular of R&D in other firms in the same industry, and of R&D in business-related services. The effect of cooperation turned out to be less clear: only the existence of cooperations with service firms and with public research institutions had a significant positive impact, whereas the cooperation with customers, suppliers and with other firms have had no effect on patenting.

Based on a larger data set (4300 responses), Fritsch (2004) has investigated R&D-cooperation behavior and effects for 11 European regions, including Vienna, Stockholm Barcelona, South Wales and Baden amongst others. He found a considerable variation between the investigated regions regarding the engagement of firms in R&D-cooperations with customers, suppliers, service firms and research institutes, as well as differences regarding the R&D-efficiency (number of patents in relation to R&D-expenditure and R&D-employment). However, in a further analysis, he found no evidence of a positive relationship between R&D-cooperation and innovative output except for a positive effect of cooperation with R&D-institutes on patenting. In this study by Fritsch (2004), Vienna has been included as one of the investigated metropolitan regions. Its companies showed a low propensity to cooperate (with all investigated types of partners). This finding is in line with the above mentioned study by Dachs et al. (2004) for Austria. However, the companies in Vienna exhibited a relatively high innovation output (patents) of their R&D-activities (R&D-expenses, R&D-employment). The investigated Viennese firms, thus, turned out as quite efficient regarding their R&D-activities in comparison to the other European regions.

Arndt and Sternberg (2000) have studied the relationship between cooperation and the performance of companies (measured by the growth of employment and turnover, the share of turnover with innovative products, and the export ratio). They found that cooperative firms are more successful in all of these categories. The strongest relationship, however, refers to the share of innovative products and the export rate. In a second, more descriptive analysis, they also differentiated between regional and extra-regional cooperation as well as types of innovation. They have shown that incremental innovations are not related to cooperation, whereas firms with high shares of new products are more often engaged in both intra- and extra-regional cooperations. More radical innovations (completely new developments) were higher in the case of firms with mainly interregional cooperation.

Based on the REGIS survey, Kaufmann and Tödtling (2001) have investigated types and location of innovation partners of 517 firms in seven regions of Europe and analyzed their effects on innovation activity distinguishing between more advanced and incremental innovations. Applying a binary Logit model, they found that only three types of innovation partners had a significant positive effect on the introduction of products "new to the market"-suppliers, consultants, and universities. Universities stimulated or enabled firms to introduce more advanced innovations, whereas contract research organizations had no positive effects in this respect. "Pure" science, consequently, seemed to be more effective in stimulating advanced innovations than applied research focusing on commercialization. The generally most frequent innovation partners—the customers—had neither a positive nor significant influence on the introduction of advanced innovations. However, other partners from the business system—suppliers and consultants—did have such a positive influence. They seemed to transfer important technology and know-how to innovating firms, enabling them to introduce more advanced innovations. On the contrary, institutions particularly designed to act as intermediaries between science and industry like technology transfer organizations did not seem to be effective in stimulating advanced innovations.

Interesting insight can also be gained from recent studies based on social network analysis (see e.g. Quimet et al., 2004; Graf, 2006; Giuliani, 2007) which relate the innovative performance of companies to the configuration of networks and to the position of companies within such wider networks (using e.g. measures of between-ness and centrality). Quimet et al. (2004) have studied the Quebec optics and electronic cluster based on interviews of 22 firms. They found that radical innovations were enhanced by diversified networks based on weak (non-frequent) ties with firms and other actors of the regional innovation system. Relevant for the innovation performance was the role of firms as gatekeepers and intermediaries (“between-ness”) in the network. These results differ to some extent from the findings by Hagedoorn et al. (2005). Studying a large international sample of more than 3000 R&D-partnerships in four high-tech industries, the authors found that a configuration of strong R&D-network ties (characterized as solid, reciprocal, dense, and long-term) within an international setting of cultural diversity were beneficial for technological performance in the investigated sectors. There are a number of further sectoral studies for chemicals, biotech, telecom, and semiconductors regarding the role of networks for innovation (for an overview, see Grodal, 2004; Powell and Grodal, 2005). For the sake of brevity, we will not deal with results of these studies here, although they often have further interesting findings and insights regarding the questions analyzed.

The following propositions can be derived from the literature review:

- There are no clear and general results regarding the relationship between networking and innovation. Findings seem to depend on the specific circumstances and conditions, such as sectors and firm sizes covered, countries and regions, and time period investigated. Despite such complexities and contingencies, there are some findings in the literature which might be of a more general nature.
- The propensity to engage in cooperation and networks in the innovation process seems to depend on a number of factors such as firm size (larger firms cooperate more often), R&D-intensity (positive influence), and sectoral affiliation (high-tech firms cooperate more often). There are no clear findings regarding the impact of the location of firms on their cooperative behavior, however.
- Regarding the influence of networking (cooperation) on innovation, the literature review does not reveal clear results. Cooperation with universities and research organizations seems to have a positive influence on more radical forms of innovation (including patenting and products new to the market). Cooperation with customers and suppliers tends to have a less clear influence on innovation performance. If there was a positive impact on innovations identified, these were often of an incremental character.
- The role of geography for innovation and networking is also far from clear. The location of companies seems to have no strong impact on innovation once other factors such as firm size, sector, and R&D-intensity have been controlled for. Also the importance of geographic proximity for innovation cooperation remains unclear. There is the finding, however that geographical proximity supports knowledge links to universities and research organizations, and that links of firms to universities support more radical forms of innovations.

4. Innovation and knowledge interactions: evidence for Austria

In this section, the relationship between knowledge links and the innovation output will be analyzed empirically for Austria. The knowledge links are regarded as a potential input in bringing forward innovations as an output. Kaufmann and Tödtling (2001) have shown that existing relationships with the science sector improve the capability of firms to introduce more advanced innovations. Here, we will extend on this work by further differentiating the relationships by the type of the knowledge interaction and the innovation output.

4.1. Methodology and data base

The following results are based on a telephone survey of Austrian firms in specific sectors conducted in 2001 on the course of the RINET-project (Kaufmann et al., 2003). The research project RINET (“Räumliche Innovationssysteme und Internet”, supported by the Austrian National Bank) was undertaken by the authors from 2000 to 2003. It has investigated to which extent the use of the Internet has changed the structure and scope of innovation relations of companies in Austria. In this survey, a stratified random sample of 1200 companies was drawn from a population of about 10,600 Austrian firms. The sample included 800 firms from the manufacturing sector (with more than 10 employees) and 400 from the service sector (with more than 5 employees; see Table 1). From this sample of 1200 firms, some 400 have participated in a telephone survey based on a standardized questionnaire (33% overall response rate). The 400 respondents included 320 firms from manufacturing (40% response rate) and 80 from knowledge-intensive business services (KIBS: 20% response rate; see Table 1).

The manufacturing sector was considered in total but was stratified regarding sector and firm size. High-technology sectors and larger manufacturing firms (more than 250 employees) are overrepresented in the sample and among the respondents. Table 1 shows differences in the structure of the population of firms, the sample and respondents in this respect. The high-technology sector and the group of larger manufacturing firms

Table 1
Structure of population, sample, and responding firms

	Population (no. of firms)	Share of population	Sample (no. of firms)	Share of sample	Respondents (no. of firms)	Share of respondents	Response rate (% of sample)
Manufacturing (NACE 15–37)	**6911**	65.1	**800**	66.7	**320**	80.0	40.0
Mf > 250 employees	**484**	6.5	**240**	20.0	**97**	24.3	40.4
High-tech manufacturing (NACE 24, 32, 33, 34)	**537**	5.1	**240**	20.0	**96**	24.0	40.0
Other manufacturing	**6374**	60.1	**560**	46.7	**234**	58.5	41.8
KIBS (NACE 72, 74.2, 74.3)	**3700**	34.9	**400**	33.3	**80**	20.0	20.0
Total	**10611**	100.0	**1200**	100.0	**400**	100.0	33.3

Table 2
Composition of respondents ($n = 400$)

(A) 320 firms in manufacturing (NACE 15–37) with more than 10 employees	
Shares of firm size classes:	
10–49 employees:	76 Interviews (23.7%)
50–249 employees:	147 Interviews (46%)
More than 250 employees:	97 Interviews (30.3%)
Shares of high-tech sectors:	
96 interviews (30%) from following sectors:	
NACE 24	Chemicals and chemical products
NACE 32	ICT
NACE 33	Medical instruments, optical instruments
NACE 34	Transport equipment, vehicles
(B) 80 service firms with more than 5 employees from the following sectors:	
NACE 72	Data and software, computer services
NACE 74.2	Architecture and engineering
NACE 74.3	Technical, physical and chemical analysis and testing

were deliberately overrepresented in the sample in order to arrive at sufficiently large numbers of respondents in these categories which would allow further disaggregation, statistical analyses, and tests.

The definition of high-tech sectors was based on the European Innovation Survey (CIS) as the top four sectors regarding the share of innovation expenses in turnover. They include chemicals and pharmaceuticals, ICT, medical, precision and optical instruments as well as transport equipment and vehicles (see Table 2). From the service sector only knowledge-intensive business services (KIBS) were selected as defined by Hipp (2000), including IT services, engineering, technical consultancy and testing (see Table 2).

As far as the location of firms is concerned, we distinguished between the Vienna urban region (the capital of Austria and its surrounding municipalities), the other Austrian urban centers (e.g. the capitals of Austrian provinces), and all other peripheral or rural locations. These types of locations represent different degrees of agglomeration and centrality in the Austrian spatial system.

The model used can be regarded as a modified knowledge production function. Regarding the innovation output (the dependent variable), the firms were asked whether they had introduced products new to the firm (1 for yes and 0 for no) and/or products new to the market (1 for yes and 0 for no). The first category refers to the adoption of innovations or to incremental changes, the second to more advanced innovations. These types of product innovations include only those new products which were already commercialized (i.e. introduced on the market), not those in the development or testing phase. The categories are not exclusive, i.e. a firm may have both types of innovation, just one of them or none. These types of innovation were considered to depend on internal and external knowledge inputs. The existence of an in-house R&D-department, the employment of researchers and the holding of patents were used as internal knowledge inputs. Regarding the external knowledge links, we have differentiated by type of relation—contract research (market), and cooperation (network) as well as by innovation partners—customers, suppliers, providers of business services, universities, technology transfer organizations, and innovation support organizations.

Firm characteristics (size and sector) and location (urban or rural) have been used as control variables. Employment (and alternatively turnover) has captured the size of the firm. The sectors have been classified into the high-technology sector, the mature manufacturing sector and the knowledge-intensive service sector. Regarding the location of the firm, the Vienna urban region, the other Austrian urban centers and all other peripheral or rural locations have been distinguished.

We have applied a binary logistic regression with a stepwise LR forward procedure including variables which are significant at the 15% level. The R^2 should not be compared with the regression R^2 as in the logistic regression the values are usually much lower. The LR-test examines whether all slope parameters in the model are equal to zero. A p-value greater than 0.05 indicates that all slope parameters are not significantly different from zero at

Table 3
Product innovation model

Dependent variable	Products new to the firm		Products new to the market	
	Coefficient	Significance	Coefficient	Significance
Firm characteristics				
High-tech sector	0.30	0.518	0.48	0.339
Service sector	**−0.66**	**0.059***	−0.51	0.139
ln (Employment)	−0.05	0.646	−0.09	0.437
Location characteristics				
Urban region of Vienna	0.51	0.129	0.36	0.293
Rural areas of Austria	0.44	0.174	0.02	0.944
Innovation characteristics				
R&D-department	**0.71**	**0.018****	**0.88**	**0.004****
Researchers	0.07	0.839	−0.27	0.448
Patents	0.25	0.424	**0.84**	**0.008****
Innovation partners				
Contract (buying of expertise)				
Business service firms	–	–	0.55	0.122
Cooperation				
Business service firms	**1.06**	**0.002****	–	–
Universities and research organizations	–	–	**1.04**	**0.005****
Constant	0.54	0.255	0.45	0.347
Test statistics				
LR-test	28.37	0.000	48.15	0.000
Hosmer–Lemeshow goodness-of-fit	6.38	0.605	8.17	0.418
Nagelkerke R^2		0.115		0.184
Correct classification (%)		77.35		76.96
N		362		369

*Significant at 5% level.
**Significant at 1% level.

the 5% level. The Hosmer–Lemeshow test is an indication of the goodness-of-fit of the model. Hereby, a p-value lower than 0.05 indicates that the model does not fit at a 5% significance level. The correct classification table states what percentage of the predicted outcomes has been classified correctly. In bold figures we have marked the coefficients that are significant at the 5% level.

4.2. Interpretation of the results

The model explaining the introduction of products that are new to the firm (comprising the adoption of products already on the market and incremental improvements) does fit arguably well (see Table 3). The existence of an in-house R&D-department improves the capability of the firm to introduce such types of innovations. Obviously, also the adoption of innovations requires some internal R&D-activities. On the first sight, this was contrary to our expectation, but actually supports the finding of Cohen and Levinthal (1990) that firms require some absorptive capacities in order to successfully adopt new technologies and to translate them into innovations. From the external partners, it is cooperation with business service firms which helps firms to introduce such less advanced type of innovation. Relevant contributions could be technology- or marketing consultancy, or other services needed in order to introduce or commercialize such innovations. Belonging to the service sector, however, has a negative impact on the probability to introduce "products new to the firm" (at a 10% significance level). This might be due to the fact that in the service sector new products are less often adopted from other firms, but rather adjusted or customized to new clients.

The model explaining the introduction of innovations that are new to the market shows a better fit. As to be expected, the existence of an in-house R&D-department is even more important and significant than for the products new to the firm. Obviously, internal R&D is a key factor for such kinds of innovation allowing the firm to generate knowledge for the development and commercialization of new products. The fact that the number of researchers has no positive impact on the introduction of advanced innovations, partly might have to do with the fact that the three variables describing the company's internal knowledge base (existence of an R&D-department, patents, and the employment of researchers) are correlated. The holding of patents is highly important and significant for this type of innovation, however. Firms introducing more advanced types of innovations, thus, try to protect their inventions from being copied by competitors. As regards external knowledge sources, it is mainly the cooperation with universities or research institutes which improves the capability of introducing products new to the market. Obviously, the more advanced innovations require collaborative research with and scientific inputs from universities and research organizations to a higher degree than less novel products.

Unexpectedly, for both types of innovations, the location of the firm had no influence on the introduction of new products. However, similar results have been found for other small countries such as the Netherlands (Oerlemans et al., 2000). We can interpret this as an already high degree of integration of the spatial system of such countries, where most regions are relatively well connected and the urban areas extend to most parts of the country. Also, no significant influence could be observed for the less intensive forms of knowledge interactions, such as information exchange and (mostly short-term) contracts. This finding might be due to the fact that these less intensive and more milieu-type relations have rather indirect effects on the innovative behavior of firms and cannot be directly related to particular innovations.

In summary, the capability of introducing advanced innovations is enhanced through the existence of an in-house R&D-department and through patenting, both enhancing the internal knowledge base of companies. In addition, firms improve their capability to introduce more advanced innovations by cooperating with universities and research institutes. This allows them to diversify their knowledge base, giving them access to complementary scientific knowledge relevant for developing novel products. Interestingly, the employment of researchers does not increase the probability for introducing advanced innovations in our model. However, the influence of this variable is partly captured by the holding of patents indicating the technical competence of the firm. Nor did the affiliation of firms to the high-tech sector have a significant influence on the introduction of new products of both kinds. This unexpected finding is consistent with the study by Dachs et al. (2004), and it indicates a certain innovation deficit within the Austrian high-tech sector. To some extent this result might be also due to the fact that "high-tech" is captured by other variables such as R&D and patents. Like in earlier studies (Kaufmann and Tödtling, 2001), but in contrast to Nieto and Santamaria (2007), we found no significant effect of knowledge links to customers and suppliers for these more advanced innovations. Knowledge links to customers and suppliers, however, might be more relevant for incremental innovations as was shown in some of the literature.

5. Knowledge interaction with universities

As we have observed in the previous section and in Kaufmann and Tödtling (2001), the relations of firms with universities and research organizations have a key relevance for bringing forward more advanced innovations and for knowledge spillovers in general (Audretsch and Feldman, 1996; Bottazzi and Peri, 2003). For this reason, we focus in a second step on the factors influencing the interaction of firms with universities and research organizations. In the following, we are going to investigate, thus, as to what extent the knowledge interactions between firms and science are influenced by company features (size and sector), their location (urban, rural) and by innovation characteristics of the firm (R&D, researchers, previous relations to universities).

The dependent variable in this model is the relation of firms to universities and research organizations differentiated by three types of knowledge interaction introduced in Section 2—information exchange (representing knowledge spillovers and milieu), contract research (market), and cooperative research (network). Explaining variables comprise the R&D-intensity of the firm, indicated by the existence of an in-house R&D-department, the employment of researchers, and the R&D-expenditures. These indicators describe the R&D-competence of the firm, considered to be an important precondition to engage into interactions with science. In addition, the occurrence of an unsuccessful research project in the past has been included as an indicator of previous learning experiences in such projects. Employment has been included as a size indicator of the firm, since previous studies have shown that larger companies, for various reasons, are more able and likely to engage in relations with science. As in the first model, three sectors were distinguished: high-technology and other manufacturing sectors, and the knowledge-intensive service sector. Regarding the location of the firm, we differentiated between the Vienna urban region, the other Austrian urban centers, and all other peripheral or rural locations.

For all three types of interaction, information exchange, contract research, and joint or cooperative research, the model fits quite well (see Table 4). It is interesting to observe that the influencing factors are rather similar for all three types of relations. Researchers seem to constitute a key channel for engaging into knowledge interactions of any kind with universities and research organizations. Obviously, the researchers are those who have the competence to engage in such relations and they are those able to understand the concepts used in science and to speak "the same language". Then, as expected, bigger firms engage more often in science–industry networks than smaller firms. This may be due to financial capabilities as well as to the fact that larger firms are less confined to applied and incremental innovation activities only, as it is often the case for small firms. SMEs, thus, have clearly more barriers for interactions with science, demonstrated also by other studies (Kaufmann and Tödtling, 2001; Asheim et al., 2003; Fritsch and Schwirten, 1998). Interestingly, the fact that the company had unsuccessful research projects in the past increases the probability of networking with universities or research organizations.

Table 4
Knowledge interaction model

Dependent variable	Interaction with universities and research institutes through					
	Information exchange		Contract research		Joint research	
	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Firm characteristics						
High-tech sector	0.12	0.724	0.47	0.204	0.27	0.445
ln (Employment)	**0.22**	**0.009****	**0.25**	**0.005****	**0.17**	**0.035****
Location characteristics						
Urban region of Vienna	−0.06	0.816	0.10	0.733	−0.10	0.716
Urban regions of Austria	0.15	0.579	0.23	0.456	−0.14	0.616
Innovation characteristics						
R&D-department	0.18	0.482	0.18	0.502	0.02	0.948
Researchers	**1.22**	**0.000****	**1.37**	**0.000****	**1.14**	**0.000****
Aborted research project	**0.78**	**0.001****	**1.02**	**0.000****	**0.82**	**0.000****
Constant	−2.17	0.000	−3.16	0.000	−2.20	0.000
Test statistics						
LR-test	69.07	0.000	82.49	0.000	55.10	0.000
Hosmer–Lemeshow goodness-of-fit	8.42	0.394	7.73	0.460	4.27	0.832
Nagelkerke R^2		0.216		0.269		0.182
Correct classification (%)		69.70		74.29		69.72
N		396		389		393

**Significant at 1% level.

Past experiences of failure, thus, seem to lead to a higher readiness of firms to look for outside help and competence for new innovation projects in order to reduce the risk of such projects.

The fact that the firm belongs to the high-tech sector does not influence the probability to engage into relations with science. This is at the first sight surprising, since we might expect that high-tech firms rely to a higher extent on scientific knowledge and on partners from universities and research organizations (Keeble and Wilkinson, 2000; Asheim and Gertler, 2005; Cooke et al., 2007). However, the more relevant variable here is the employment of researchers which enhances the absorptive capacity and the capability to interact with universities. As in the previous model, location has no influence on science–industry relations. Urban location, thus, does not lead to a higher probability of such relations once these other factors are taken into account. In the light of the literature on clusters, this is unexpected, since most universities and research organizations are in fact located in cities, many of them in Vienna. Spatial proximity, thus, does not seem to be highly important for science–industry interactions in a small country such as Austria. Firms interested in and capable of engaging in such relations seem to be doing so irrespective of their location.

It was surprising to find that there are only few differences between the types of relationships. The results for information exchange (informal link), contract research (market type), and collaborative research (network type) were not too different as can be seen from Table 4. Partly, this finding might be due to the fact that these types of interactions go parallel, i.e. firms undertaking collaborative research also may have contract research and information exchange with universities. This is reflected in a certain statistical correlation among these types of relationships. It seems as if firms, once they have overcome the barriers to interact with universities, are using various channels of knowledge exchange and not just one type.

6. Conclusions

Our findings show that different types of innovations do rely on different kinds of knowledge inputs, sources and links. More advanced innovations (products new to the market) require to a higher extent internal R&D and patenting and they are stimulated and supported by cooperation with universities and research organizations. Obviously, they rely more on scientific inputs than less advanced innovations. The introduction of products new to the firm only (adoptions, incremental changes) also requires some R&D-activities, but to a smaller extent. As Cohen and Levinthal (1990) have argued, also for this type of innovation some "absorptive capacity" of firms is needed. Regarding external relations, it is cooperation with service firms rather than with universities (i.e. practical knowledge rather than scientific knowledge) which helps to undertake such kinds of innovation.

It is interesting to find that for both types of innovations, the less binding forms of knowledge interactions, such as information exchange, have no influence on innovative activity in the models applied. This may be partly due to the fact that these less intensive relations are more difficult to capture in a standardized questionnaire. Partly, these informal relations might have more indirect effects, such as building up trust among partners and paving the way for more binding forms of knowledge exchange and cooperation.

Furthermore, the sectoral affiliation of firms and their location do not show up as significant factors for their innovative behavior. Regarding the sectors, the results indicate that innovation is not confined to high-tech industries but occurs in all investigated sectors. This is relevant for Austria which has been competitive in particular in medium-technology sectors in the past. Innovation policy, thus, should not target high-tech industries only but address a broader set of sectors (Lundvall and Borràs, 1999; Tödtling and Trippl, 2005).

Regarding location, our findings seem to indicate that there are no particular disadvantages of rural areas or smaller cities for innovation and knowledge interactions. This might be due to the fact that Austria is a small country with a well-developed transportation and communication infrastructure covering most areas of the country. If there are location disadvantages for innovation in particular regions, it is possible to overcome them by, for example, the recruitment of personnel, the engagement in distant innovation networks and the use of modern ICT (Kaufmann et al., 2003).

Knowledge links of firms to universities, thus, seem to stimulate in particular more advanced innovations. In a second analysis, we have found university links to be positively related to the size of the firm, the employment of researchers and the experience of failure with previous R&D-projects. Larger firms, obviously, have fewer barriers for interacting with universities in R&D-projects. In addition, the employment of researchers, able to understand the relevant scientific language and concepts, helps companies to overcome problems of knowledge exchange with the science system.

From our findings, we conclude that innovation policies for highly developed countries like Austria should aim at stimulating more advanced innovations instead of only incremental ones. Advanced innovations, new to the market, help to improve the competitive position of the firms in the long run and in a more durable way than incremental ones. Such policies, however, should not be targeted on high-technology industries only, but cover a broader set of sectors. Of key importance for stimulating advanced innovations is an increase of R&D-activities of firms (e.g. through tax allowances or other instruments). Related to this, the increase in the number of researchers should be supported by an increase in the supply of highly educated workforce. The stimulation of links between firms and universities or research organizations might be a third policy element. Some interesting policy instruments for stimulating university–industry links have been applied in Austria and in other countries already, such as the financial support for R&D-networks, or the brokering of partners from business and science (see e.g. Cooke et al., 2007; Trippl and Tödtling, 2007). A systematic evaluation and benchmarking of such efforts, however, is needed for introducing more effective innovation polices.

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