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Knowledge Flows Through Social Networks in a Cluster: Comparing University and Industry Links

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Abstract: Knowledge spillovers from a university to the local industry play an important role in high-technology clusters, but we know little about these spillovers. This paper examines empirically the extent of informal contacts between employees in firms and local university researchers in a wireless communications cluster. Furthermore, it analyses the features of an engineer who acquires knowledge from these informal contacts. The university-industry contacts are compared to results for informal contacts between employees in competitive firms. The research shows that the interfirm informal contacts are more numerous than university informal contacts. Likewise, knowledge is more frequently acquired from other firms than through university-industry contacts. However, not all engineers in the cluster have informal contacts or acquire knowledge through these. Engineers who have participated in formal projects with university researchers and engineers who are educated at the local university have a higher likelihood of acquiring knowledge from informal contacts with university researchers.

JEL codes: D83, O32, I23

1 Introduction

The diffusion of knowledge between firms through informal social networks has received a lot of attention in the literature on clusters. The existence of knowledge externalities is often argued to be one of the main reasons for clustering of industries (Marshall, 1920; Storper and Walker, 1989; Saxenian, 1994). The main argument is that knowledge and information are flowing more easily between organisations in a cluster than outside and across its borders. The importance of these knowledge flows has been centre of an intense discussion in economics and economic geography (Krugman, 1991; Martin and Sunley, 1996). Critics state that employees will not generally share firm-specific knowledge and only exchange general knowledge of low value that is less disadvantageous for their firm (Breschi and Lissoni, 2001). However, recent studies have shown that knowledge flows through social networks do take place and even firm-specific knowledge is shared (Lissoni, 2001; Dahl and Pedersen, 2004; Giuliani, 2007). Not all agents in a cluster have social contacts with employees in other firms, since social networks are exclusive and are created over time by individuals (Lissoni, 2001; Dahl and Pedersen, 2005; Saxenian, 2006; Giuliani, 2007).

Universities are often found to be an important part in clusters. The university is seen as a source of new knowledge (Feldman, 1994; Saxenian, 1994; Anselin et al., 1997). University research and knowledge is, somehow, flowing from the university to firms in the cluster. This knowledge diffusion can take place as formal cooperation, through mobility of graduates, and through informal social networks. The knowledge flows through social networks between employees in firms and university researchers have received less attention in the cluster literature. However, the social network between employees in firms and university researchers are also likely to consist of smaller epistemic communities. Furthermore, the evidence is mainly anecdotic or measured by a distance-to-university proxy in regression analysis. In addition, the agents involved in these networks might have different characteristics and types of connections than the agents involved in interfirm networks. The value of the knowledge shared might be higher and the agents educated at the local university might have a higher chance of acquiring knowledge compared to non-local agents.

The purpose of this paper is to study to what extent engineers in a high-technology cluster are sourcing knowledge through social networks with researchers at the local university. This paper also analyses the relationship between the likelihood of acquiring knowledge and the features of the engineers. The university-industry contacts are then compared to the interfirm social networks in the cluster. The analysis is based on data from a questionnaire survey of highly educated technical employees in the cluster of high-technology wireless communications firms around Aalborg, Denmark. The present analysis is carried out at the micro level, in this case focusing on the individual engineer, which provides a better picture of the extent of informal contacts and likelihood that the engineers receive knowledge they can use in their own job.

The following Section 2 presents the theoretical framework on knowledge flows through informal channels. Section 3 describes the case, data and methodology, while the results of the regressions analyses are presented in Section 4. The results are discussed in Section 5 followed by the conclusions in Section 6.

2 Knowledge flows through social networks between individuals

The innovation process involves interaction and knowledge sharing between co-workers within the firm to become successful. Innovation studies have found that innovation is an interactive process and the central part of the required knowledge is often difficult to codify. Therefore close interaction among actors is important in the innovation process (Lundvall, 1992; Lundvall and Johnson, 1994). An important element of an R&D employee's work is the collection, diffusion and processing of information. The success of this process depends on the employee's ability to acquire the needed information through the appropriate networks (Allen, 1984; De Meyer, 1991). However, the informal networks of R&D employees are often different from the firm's communication structures and also cross its boundaries. In addition, the knowledge flows between individuals are more often a result of the employees' personal initiative than formal organisational structures (Allen and Cohen, 1969; Allen et al., 2007; Parker et al., 2002).

It can create problems when an agent decides to share knowledge through informal channels with employees in another firm or a university. This relates to the asymmetry in knowledge flows. Firms clearly gain from knowledge spillovers when it receives information, but when its own R&D is being shared it erodes their competitive advantage. Despite the fact that knowledge flows initially are a disadvantage for the firm, several studies have shown that firms generally benefit from knowledge spillovers and that informal exchange of information between agents in different organisations is frequent in the innovation process (Rogers, 1982; Allen, 1984; von Hippel, 1987; Ingram and Roberts, 2000).

Geographical, cognitive and social distance is important for knowledge flows between individuals. Several researchers have argued that the short geographical distance in a cluster should increase the sharing of knowledge, while others have stressed the importance of short cognitive distance (see e.g. Storper and Walker, 1989; Saxenian, 1994; Audretsch and Feldman, 1996; Maskell et al., 1998). However, being employed in a cluster firm does not imply a short cognitive distance and that an agent gains access to knowledge flows. It is necessary to be a part of a social network and have informal contacts with other employees in the cluster. These contacts are personal and are created over time. Likewise, it is not all agents that have informal contacts across firm boundaries within the same industry or with university researchers in the region (Breschi and Lissoni, 2001; Lissoni, 2001).

The strength of the ties and the cohesion in the social networks are important for the sharing of knowledge. A high degree of cohesion will provide the agent with redundant information, while agents that spans structural holes i.e. connect two nodes that are not connected, can receive new information (Granovetter, 1973; Burt, 2004). In cohesive social networks the agent receives information that is more reliable and firm-specific, while the weak ties increase the total amount of new non-redundant technical knowledge, but also increase uncertainty (Ingram and Roberts, 2000; Ingram and Roberts, 2000; Cowan and Jonard, 2003; Fleming et al., 2007).

However, not all types of knowledge can be transmitted easily. It takes time and usually requires intermediary cognitive capacities and that the agents have related skills. To be able to understand and process the information the receiver needs to be within the same knowledge domain and know the competence of the field (Wenger et al., 2002). Thus, the agent's ability to exploit the external knowledge depends on absorptive capacity (Cohen and Levinthal, 1990). Agents with prior related knowledge often have a better ability to absorb, diffuse, and apply externally received knowledge, i.e. they have higher absorptive capacity. In Giuliani's (2007) study of knowledge networks in clusters in the wine industry, she finds that the head of production in a firm with high absorptive capacity is more densely connected in knowledge networks with other firms in the cluster.

Hypothesis 1: Employees with a higher absorptive capacity are more likely to acquire knowledge through informal contacts.

Trust is a key issue in knowledge transfer, since the agent looses control of the information when it is shared and the agent also expects that the receiver reciprocates the favour in the future. Trust is established by familiarity and numerous interactions between agents or it could be created through indirect ties if they have social contacts in common (Piore and Sabel, 1984; Pyke et al., 1990; Maskell et al., 1998; Løvås and Sorenson, 2004). Individual face-to-face contact is important in complex problem solving activities where information needs to be transferred. To fully understand the information, the receiving agent needs to know the context of the information e.g. background, application, and function (Allen, 1984; De Meyer, 1991). Working on a joint project within or between organisations increases the trust between employees and the collaborative effort builds informal networks (Allen et al., 2007; Fleming and Frenken, 2007). Cross et al. (2002) argues that a collaborative project is a method to create informal networks between individuals in an organisation that can be used in future projects. Based on studies of social networks between employees in the Brescia mechanical industry, Lissoni (2001) adds that the social networks between individuals can arise from successful formal cooperation with suppliers or competitors

Hypothesis 2: Employees previously involved in formal projects with employees from other organisations have a higher likelihood of having informal contacts and acquiring knowledge.

A wide range of processes and factors influence the possibilities for knowledge flows through social networks between individual agents in a cluster, but two basic processes are needed: First, the agents must be connected to each other and second, they must trust each other to exchange information. The mobility of agents between organisations can potentially be important for knowledge sharing, since it affects the evolution of social network structures (Breschi and Lissoni, 2003; Fleming and Frenken, 2007). Likewise, Granovetter (1973) argues that job mobility contributes to the building of social networks by creating new links and bridging the structural holes between organisations.

Hypothesis 3: Mobility has a positive effect on the likelihood of having informal contacts.

Mobility also generates know-who i.e. who knows what and where do they work. When facing a problem an agent is likely to also think of former colleagues who might know the solution. If the agents used to work together and share information when they were colleagues, they might be more likely to exchange information again. The experience of working together can facilitate future knowledge flows, since common coding schemes and trust already exist (Almeida and Kogut, 1999; Maskell et al., 1998).

Hypothesis 4: Mobility has a positive effect on the likelihood of acquiring knowledge through informal contacts.

The sociological factors are similar for agents that have informal contacts with employees in other firms (interfirm contacts) and agents with informal contacts with university researchers (university-industry contacts) in a cluster. However, there are also differences.

2.1 Knowledge flows between employees of different firms and between employees and university researchers.

The knowledge flows between firms can take different forms, such as knowledge sharing or mobility of employees and it uses various channels, such as know-how trading, collective invention, and licensing (Appelyard, 1996). Von Hippel (1987) argues that the knowledge sharing through informal networks is a form of trading know-how, where employees in different firms give advice to technical problems or share information with each other. The receiver of the information is expected to reciprocate the favour in the future (Schrader, 1991).

The transfer of knowledge represents a potential cost to the transferring firm, since it might loose possible monopoly rents if the employees decide to share valuable knowledge (Schrader, 1991; Appelyard, 1996). This depends on the redundancy of the information in the network. Breschi and Lissoni (2001) are critical of the concept of localised knowledge spillovers. They argue that employees will not jeopardise the firm's competitive advantage, but are sharing minor ideas and information. Therefore it is necessary to distinguish between receiving information or useful knowledge that can be applied in the agent's work. Furthermore, Breschi and Lissoni (2001) argues that knowledge does not automatically spill over, but is diffused in communities of practitioners through social networks. The agents are a part of the same knowledge domain defined by the key technologies and knowledge base in a cluster, but there are several distributed communities of practice. These consist of agents working within the same domain and facing similar problems, but knowledge flows also require engagement and interaction between the agents and an alignment of norms, codes, and identity (Wenger et al., 2002). The agents interact across firm boundaries through social networks that require cognitive and social proximity that arise from shared work or study experience and frequent face-to-face interaction and socialising (Breschi and Lissoni, 2001).

Local trade and industry associations can act as a platform for the formation of informal networks. Saxenian (1994) argues that industry and trade associations helped strengthen Silicon Valley's social and professional networks by hosting meetings and trade shows. The integrative role of the trade associations emerged when they changed their purpose from being traditional lobbying business associations and started to sponsor seminars and educational activities. The meetings in the associations then became a source of market and technical information and an opportunity to stay in contact with old colleagues (Saxenian, 1994). In her book on the new Argonauts, Saxenian (2006) argues that professional and technical associations are very important for the immigrant technology workers in Silicon Valley. The various associations for immigrant groups are very active in facilitating professional networking and information exchange.

Universities are often seen as an important source of knowledge in high-tech clusters (Feldman, 1994; Saxenian, 1994). Famous examples of prominent clusters with leading universities, such as Stanford in Silicon Valley and MIT in Boston Route 128 have shown that universities often play an important role in clusters. The universities have traditionally had two missions: Basic research and training, but recently there has been an increasing focus on the third mission: Commercialisation of knowledge. While some traditional universities have focused mainly on the advancement of knowledge there are many universities, where cooperation with industry has become common (Etzkowitz, 1998).

There are many direct and indirect interactions between universities and firms. They interact through formal research projects (e.g. joint research projects or contract research), mobility of scientists, training, consultancy, education of highly skilled graduates, and informal contacts between employees in firms and university researchers (Lawson, 1999; Mueller, 2006). Anselin et al. (1997) argues that the public nature of basic research at the university results in positive externalities to the firms through knowledge spillovers. The firms locate close to the universities, often in nearby science parks, and tap into the university research or benefit from knowledge spillovers (Feldman, 1994; Saxenian, 1994; Anselin et al., 1997). These knowledge flows are often measured by patent citations, academic papers, and size of academic staff or university research spending in regression models.

Breschi and Lissoni (2001) are critical of the idea of automatic knowledge spillovers from universities to local firms. They argue that research at universities is more basic than applied and that knowledge is flowing through pecuniary channels, such as production of graduates, consultancy, joint research, sponsored research, formal research projects, start-ups, and mobility. Furthermore, they argue that new knowledge from basic research often is tacit, which can not be transferred through informal contacts, since it is necessary to build a competence to identify and understand this specific knowledge. Therefore it can only be recreated and transferred by the researchers through mobility or formal contracts. However, both industry and university researchers are active in applied and fundamental scientific research (Rosenberg, 1990). In a cluster with many firms working within similar technologies, overlaps in the employees' knowledge base, and a common labour market, the university is only to a lesser extent a source of knowledge through informal contacts. This can be explained by a size difference in number of possible contacts and the specificity of the knowledge with regard to its context. The larger size of the private employment compared to the number of university researchers will make the interfirm contacts more widespread than university-industry contacts.

Hypothesis 5: The interfirm informal contacts are more frequent than university-industry informal contacts.

In their study of cooperation between university researchers in science-based fields and firms in Germany, Meyer-Krahmer and Schmoch (1998) find that the central linking element is the exchange of knowledge in both directions. They argue that university research in science-based fields is not exclusively basic research, but also applied research. They find that academic researchers' rank collaborative research and informal contacts higher than contract research. The ranking of advantages of interaction with firms reveals that the researchers rank knowledge exchange almost as high as additional funds. They prefer collaborative research with bi-directional knowledge flows. A considerable disadvantage is the short-term orientation of firms. Meyer-Krahmer and Schmoch (1998) argues that university researchers benefit from interaction with firms, since these also conduct R&D and produce new knowledge that the university researchers need to support their own academic career.

University researchers are working within the same knowledge domain as the agent in the private firm, but the latter is more likely to be involved in applied research. There are hundreds of routine questions and these can only be answered by agents in similar jobs. Therefore the transfer of tacit knowledge requires a joint understanding of the context that the knowledge is a part of. If it is embedded in a learning-by-doing context it might be even more difficult. In a cluster where the firms are working within similar technologies there are many agents with similar jobs, but many firms are still working in different parts of the value chain. This suggests that even though social networks are widespread there are limits to the knowledge diffusion, since knowledge can be firm-specific, industry-specific or job-specific. Therefore the usefulness and value depend on the similarity of the agents' job functions. The different types of knowledge and job functions in firms and university make the agent more likely to acquire useful knowledge from other firms that can be applied in the agent's work.

Hypothesis 6: An employee's likelihood of acquiring knowledge through interfirm informal contacts is higher than for university-industry informal contacts.

Fleming and Frenken (2007) analyses the evolution of inventor networks in Silicon Valley and Boston. They argue that the universities play an important role as a creator of networks in clusters. The educational programs at the local universities create institutional glue by creating a connection between agents and initiating the formation of ties. Especially, the mobility of graduates from Stanford and IBM's postdoctoral programs helped build inventor networks within the region (Fleming and Frenken, 2007). In addition, they argue that the inventor network in Silicon Valley grew larger than in Boston partly because the MIT graduates often left the region, while the Stanford graduates took local employment. The educational background is potentially an important factor in shaping the agents' social networks (Breschi and Lissoni, 2001). The graduates from the local university have former classmates working in the cluster, have friends in common (indirect ties) or simply know who to contact at the university if they face a problem.

Hypothesis 7: Employees educated at the local university are more likely to acquire knowledge than non-local employees through interfirm and university-industry informal contacts.

3 Survey data

To analyse knowledge flows through informal channels in a cluster a questionnaire was sent to engineers and computer scientists in the wireless communications cluster in North Jutland, Denmark. Wireless communications is a high-technology industry with a fast technical change. The cluster is defined by a common knowledge domain that includes technologies related to electronic signals transmitted by radio waves. This includes equipment for wireless maritime, land, mobile, and satellite communications.

The history of the cluster dates back to the 1960s when the first firm in the cluster diversified from production of consumer electronics into equipment for maritime radio communications. The company became very successful and many firms was founded as spin offs during the 1970s and 1980s. Some of them diversified into mobile communications and the cluster received considerable attention at the Cebit fair in Hanover in 1992, when two firms from North Jutland through a joint research effort presented a GSM mobile phone among only a handful of firms in the world. The cluster experienced a high growth in number of employees and firms during the 1990s and several multinational companies entered the cluster. The profile of the cluster also broadened horizontally, since some firms entered or diversified into various communications technologies and vertically with the entry of service providers, software companies, and chip-set R&D companies. For an overview of the history of the cluster see Dahl et al. (2005) and Dalum et al. (2005).

The local Aalborg University (AAU) was founded in 1974 and has today 13,000 students and 1,700 employees in Humanities, Engineering, Health, Natural, and Social Sciences. Aalborg University was until 2000 the one of only two universities in Denmark that offered engineering MSc's and in the 1990s approximately 50% of the Danish electronic engineers graduated from Aalborg University. From its establishment Aalborg University has been very active in cooperation with private firms and it participates in many networks and joint research projects. The number of university researchers in various fields of electronics totals almost 300 persons. The research within wireless communications technology was mainly profiled by Centre for Personal Communication (CPK), which from 1993 to

2002 was an important international actor on the research scene in wireless technologies. CPK consisted of 50-60 researchers.

The questionnaire was mailed to the members of the NorCOM association of wireless communications firms in North Jutland. 25 of approximately 35 firms in the cluster were members of NorCOM. The non-members were generally smaller firms and newly founded firms. NorCOM was founded in 1997 as a club for communications technology firms, Aalborg University, and the local science park. In 2000 NorCOM became a formal association with a board of directors. The main role is to represent the interests of the group like a traditional business association, but it also arranges four meetings every year about technical and industry issues. It is mainly managers and university researchers that meet and discuss the development of the wireless communications industry. The Danish Society of Engineers (IDA) is also present in the region, but it is mainly focused on traditional trade union activities. The two trade associations do not appear to play a similar role as a platform for knowledge exchange and network formation for individual employees as the trade associations in Silicon Valley.

To improve the response rate and get the permission of the managers to distribute the questionnaire among their employees the respondents were given full anonymity. Therefore it is not possible to identify individual respondents and firms. Managers of 19 firms agreed to distribute the questionnaire to engineers, computer scientists and employees with a higher technical education in their firms. The questionnaires were sent to 791 employees and 346 responded, which gives a 44% response rate. The survey was carried out in November and December 2001[1]. A consultancy report from 2002 indicated that the total number of engineers etc. was approximately 1,000 (COWI, 2002).

After questions about the respondent's age, gender, state of living, nationality, job function, educational background, experience, job changes and movement etc. they were asked questions about networks. They were asked if they previously had been involved in formal collaboration projects (e.g. joint development projects) with employees from other communication technology firms in North Jutland and if it was suppliers, customers, or competitors. Then they were asked if they have an informal contact with an employee working in another firm in the cluster. In the questionnaire an informal contact is defined as a contact with employees from other communications firms in North Jutland or Aalborg University that is not a part of a formal agreement. They were also asked to describe the type of connection: Former colleagues, classmates, private friends or other. Afterwards, they were asked if they acquired knowledge through this contact which could be used in their own work and the type and value of this knowledge. Then they were asked about previous participation in formalised projects with researchers at Aalborg University and questions about informal networks, acquisition of knowledge and questions about type of knowledge and value related to university-industry informal contacts.

In the questionnaire they were asked if they acquire knowledge that can be used in their own work through their informal contacts. As stated in the theory section, it is necessary to distinguish between receiving information and useful knowledge that can be applied in the respondent's work (Giuliani, 2007). The respondents may also receive a lot of information with a social content or small ideas and rumours about firms as described by Breschi and Lissoni (2001).

Logistic regressions are used to analyse the hypotheses on the probability of having an informal contact and acquiring knowledge. Several variables are used in the regression of which most are

[1] This paper is based on the dataset used in Dahl and Pedersen (2004, 2005).

derived directly from the questionnaire. The dependent variables are all derived from the questionnaire: If they had an informal contact with employees in other firms (yes/no) or with university researchers in the cluster (yes/no). If they acquired knowledge through the interfirm informal contacts (yes/no) or university-industry contacts (yes/no). The value of the knowledge acquired (low, medium or high) from the two types of contacts.

The independent variables are: Participated in formal projects refers to the question about participation in previous formal projects with other firms (yes/no) or university researchers in the cluster (yes/no). Previous participation in formal projects is expected to be positive for the likelihood of having an informal contact and acquiring knowledge. Educational institution is a dummy variable stating whether they are from Aalborg University or from other institutions (Aarhus University, Denmark's Technical University, Copenhagen University, Roskilde University Center, a technical college, other institution, or foreign institution). Educational institution is expected to have a positive effect because the local university acts as a platform for network creation (Hypothesis 7). R&D as main job function (yes/no) is a dummy variable indicating if the respondent has answered that his/her present most important job function in the firm is in research and development. The other categories are production, management, or marketing, but the R&D jobs account for 75% of the sample. There are also three types of connection dummy variables: Contact with former colleagues, former classmates and private friends. These are based on who the respondent is contact with: Former colleagues, classmates, private friends, and other.

Absorptive capacity is often measured as a combination of the level of education and experience in the industry. However, the sample consists of highly educated technical personnel and almost half of the sample is engineering MSc's. Experience can be measured from the questionnaire as years in current workplace, years of experience in wireless communications, years of work in firms in the cluster or years since graduation. The latter is used to test for the effect of the agent's absorptive capacity in Hypothesis 1, since the engineer might have gained experience in other industries. The effect is expected to be positive.

Mobility can also be calculated in various ways based on information from the questionnaire: Number of job changes, number of different workplaces since graduation. However, there is no information about when the engineer changed job and how long he/she stayed at the different workplaces. In addition, the effect of mobility may change as a result of frequent job shifts and decrease with number of years since last job change. In the regressions mobility is calculated as number of job changes between firms divided by experience. Mobility is expected to have a positive effect on the likelihood of having informal contacts and acquiring knowledge (Hypothesis 3 and 4).

Table 1 shows the distribution of variables for interfirm and university-industry contacts respectively.

INSERT TABLE 1

The first set of logistic regression models analyse the probability that an engineer has an informal contact with employees in other firms or university researchers in the cluster, see Table 4. The independent variables are participation in formal projects (Hypothesis 2) and mobility (Hypothesis 3). The control variables are: Educational institution; experience as a proxy for absorptive capacity; R&D job to control for job function.

The second set of regression models analyse the probability that an engineer acquires knowledge through informal contacts, see Table 5. The independent variables are absorptive capacity (Hypothesis 1), participation in formal projects (Hypothesis 2), educational institution (Hypothesis 7), and mobility (Hypothesis 4). The control variables are R&D job and dummy variables for contact with former colleagues, classmates, and private friends.

The third set of regression models analyse the probability that an engineer acquires knowledge of high value, see Table 6. The models include similar factors as the regression models for acquiring knowledge.

The analysis has some empirical and methodological limits. It is a cross-sectional dataset, the respondents are anonymous, and it is conducted within a single industry in a narrowly defined cluster. It is not possible to control for company effects on the employees' informal contacts. Some companies might have a strict management regime that discourages external contacts. A multinational company might make their employees more biased towards having informal contacts with employees in other parts of their own organisation. The anonymity also makes it impossible to identify whom the engineers are in contact with, their job position, and where they work. However, it was a necessary condition to get the questionnaire distributed to the highly educated technical personnel in the firms and to improve the response rate. Therefore it is not possible to map the extent of the network using the methodology of social network analysis. The position in the network can have an effect on the likelihood of acquiring knowledge (Giuliani, 2007). In addition, there is no time dimension that could show how these networks evolve and change over time and the amount of knowledge diffused through informal contacts. This creates some limitations for the causality, but we do ask for previous participation in formal projects and if they currently have informal contacts.

This study also has some advantages. The case is a narrowly defined cluster of high-technology firms within the field of wireless communications. The companies are R&D intensive and the highly educated technical engineers are the most important resource in the R&D process in the firms. The engineers' sourcing of knowledge through informal contacts can have an effect on the firms' performance and the evolution of the cluster. The questionnaire was mailed to individuals and asked questions about their informal contacts and if they acquired knowledge that could be used in their own job. Other studies often ask a technical manager about the employees' informal contacts, but the managers do not know the extent of their employees' informal network (Allen et al., 2007). The extent of knowledge flows is likely to be more precise because the respondents are asked if they acquire useful knowledge (Dahl and Pedersen, 2004).

4 Results

4.1 Interfirm versus university-industry knowledge sharing

The demographics of the respondents show that the sample consists mainly of younger men (95%) with an average age of 33 years (standard deviation 6.6 years). 52% of the respondents are graduates from Aalborg University. The largest educational group is engineering MSc's (47%) followed by bachelors of engineering (34%), while 3% have an MSc in computer science and the remaining has another type of higher technical education. The average work experience in the cluster is almost 6 years, while 62% have worked in the cluster for 5 years or less. They have worked on average 3.6 years in their current firm in their current job. The respondents main job function is primarily in research and development (75%) followed by management (16%), production (5%), and marketing (4%).

Approximately 1,000 employees in the cluster have a higher technical education, while the university employs 50-60 researchers in wireless communications technology and 300 in electronic engineering. Thus, Hypothesis 5 argues that due to the larger size of the industry compared to the specialised university research groups the interfirm informal contacts are more frequent than university-industry contacts. Table 1 shows that 75% of the respondents answer they have at least one informal contact with employees in other firms in the cluster. Interfirm informal contacts are, as expected, widespread while 29% respond that they have an informal contact with researchers at the local university. Thus, Hypothesis 5 can be validated. 22% of the respondents have no informal contacts, 49% only have interfirm contacts, 3% only have informal contacts with university researchers, and 26% of the respondents have both types of informal contacts. The share of engineers with any type of informal contacts is very high. Lissoni (2001) finds that only 36% of the engineers in the Brescia mechanical cluster had informal contacts with engineers in other firms in the cluster. However, the Brescia cluster consists of four mature manufacturing industries and covers a wider geographical area, while the firms in the wireless communications cluster are more or less working within the same high technological domain and within close geographical proximity. Furthermore, there are many reasons for having an informal contact with employees at the university and other firms. These social networks have various functions and many have mainly a social content.

In the questionnaire the respondents were asked if they acquired knowledge that could be used in their own job. To investigate whether the engineers are more likely to acquire useful knowledge through informal contacts with employees in other firms compared to informal contacts with university researchers these were compared, see Table 1. 31% of the respondents acquire useful knowledge through interfirm contacts, but only 13% acquire useful knowledge through university contacts. Thus, the university contacts are less frequent than interfirm contacts and the respondents also acquire useful knowledge from university contacts less frequently. The interfirm informal contacts are more important in absolute numbers, but this is mainly an effect of the size difference. Taking the lower frequency of the university contacts into account 41% of the respondents who have interfirm contacts receive useful knowledge, while 45% of the respondents with university contacts receive knowledge from that source. Thus, a marginal higher share of the engineers who have a university contact acquire knowledge compared to interfirm contacts[2]. As a result it is not possible to confirm Hypothesis 6.

Table 1 reveals that only 2.6% of the sample acquires high-value knowledge from interfirm contacts compared to 2% for university contacts. The relative share of respondents who acquire high-value knowledge is higher for university-industry contacts, but the number of observations is very low. 11% of the sample responds that they acquire knowledge of low value for interfirm contacts and 3.5% for university contacts. Thus, a higher share of respondents receives knowledge of low-value than high-value. However, half of the respondents who acquire knowledge from either interfirm or university contacts value this as being of medium value.

The informal contacts between employees in different firms are more frequent and knowledge is acquired through these contacts more frequently compared to university contacts in absolute numbers. However, the normalised share of engineers who acquire knowledge from interfirm contacts is not significantly different from university-industry contacts. The interfirm informal contacts are still a more important source of knowledge in the cluster, but this appears to be a size difference.

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[2] The relative proportion of engineers who acquire knowledge through informal contacts is not significantly lower than the share of engineers who acquire knowledge through university contacts.

The respondents were also asked to describe the type of knowledge they receive: General knowledge, technical knowledge on standard equipment, technical knowledge on new products and other. Table 2 shows that the knowledge is mainly described as general knowledge (78-9%). The engineers mainly receive technical knowledge on new products through interfirm contacts. This indicates these are a source of applied firm and industry-specific knowledge.

INSERT TABLE 2

Table 1 also reveals with whom the respondents are in contact. For interfirm contacts, almost 66% are in contact with former colleagues (50% of total sample). This indicates that trust and job changes are important for the creation of informal networks. The relationships built by engineers working together seem to last longer than the actual time they work together. This result is consistent with the arguments of Breschi and Lissoni, 2003. However, for university-industry contacts only 23% (7% of total sample) are in contact with former colleagues at the university. This indicates lower university-industry mobility. For the interfirm contacts 65% of the respondents with informal contacts have contact with former classmates, while 46% of the university-industry contacts have contact with former classmates. Thus, many informal contacts are created at the university between students and kept after graduation. 48% answer that they are in contact with private friends for interfirm contacts and 42% for university–industry contacts.

Lissoni (2001) argues that many informal contacts arise from formal cooperation between firms. Thus, working together creates the base for further interactions in the future. This survey reveals that 20% of the respondents have previously participated in formalised projects with other firms in the cluster. 25% of these have participated in projects with suppliers, 29% with customers and 36% with competitors. For formal projects between university and industry 13% of the respondents have been involved in formal projects with researchers at the local university. The high share of engineers involved in formalised projects with other firms or university can be an important factor in the creation of social networks. Almost 87% of the engineers who previously have participated in formal projects have interfirm informal contacts. This relation is less for university-industry contacts, where only 47% of the former participants in formal projects have an informal contact with university researchers. The difference in the frequencies can an effect of the more applied nature of interfirm collaboration projects or maybe the respondents simply participated in many formal projects. In addition, Meyer-Krahmer and Schmoch (1998) finds that the firms have short-term orientation, while university researchers prefer basic research projects with a more uncertain and long run perspective.

4.2 Factors that characterise an engineer who acquires useful knowledge

Table 3 shows a correlation matrix and descriptive statistics for the variables used in the logistic regression analysis. The correlation matrix reveals that having a R&D job is negatively correlated with knowledge indicators and experience. In addition, experience is positively correlated with formal projects, while it is negatively correlated with educational institution. This holds for both types of contacts. It appears that many young engineers from Aalborg University are employed in R&D jobs. This effect can be explained by the rapid employment growth in the cluster in the late 1990s and onwards.

INSERT TABLE 3

Two logistic regression models were estimated on the probability that a respondent has informal contacts with employees in other firms in the cluster and the local university subsequently (Models 1a-b).

INSERT TABLE 4

Table 4 shows that three factors have significant effects on the likelihood of having informal contacts with employees in other firms. Engineers who have participated in a formal project with other firms in the cluster or engineers who are educated at Aalborg University are more than double as likely of having an informal contact compared to engineers who have not participated in formal projects or are educated at different institution. Working together on joint projects builds trust and help create informal network. There are also three significant factors for university-industry contacts. Engineers who have participated in a formal project with researchers at Aalborg University have a significant and positive effect on the likelihood of having an informal contact. The variable educational institution is also positive and significant. Thus the local university acts as a platform for the creation of informal networks. This result is consistent with the findings of Fleming and Frenken (2007) on inventor networks in Silicon Valley. However, the effect of educational background is stronger for university-industry contacts. The engineers from Aalborg University are almost five times more likely to have contacts with university researchers (odds ratio 4.77) compared to other engineers. During their education they learn to know many of the university researchers and some of them keep in contact. Mobility is also insignificant for university contacts. Thus, it is not possible to confirm Hypothesis 3. The variable for work experience is not significant in Model 1a, but has a negative and significant effect in Model 1b. The marginal effect of experience on the probability of having an informal contact reveals that the probability decreases 1.4% for each year of extra experience. A newly graduated engineer from Aalborg University keeps in contact with researchers at university e.g. the former supervisor or teacher. However, over time they are likely to loose contact as the engineer becomes more involved with engineers in the firm or other firms. The likelihood ratios show that the null hypothesis that all coefficients are equal to zero can be rejected (Allison, 1999). Thus, both models are highly significant and the concordant ratios are 65.9% and 75.2%, indicating that the models are better to predict outcomes than the 50/50 baseline. Tests for multicollinearity using the Variance Inflation Factor (VIF) method show no sign of multicollinearity.

The logistic regressions in Models 2a-d investigate the probability that an engineer acquires knowledge that can be used in his/her own work. Table 5 shows that the factors are quite similar to the previous models. Engineers who have participated in formal projects with other firms in the cluster are more likely to acquire useful knowledge. The participation in formal projects has a significant and positive effect on the likelihood of acquiring knowledge with an odds ratio of 2.3 and a marginal effect of almost 9%. Thus the effect of formal projects is strong and it is a method to build informal contacts (Cross et al., 2002). Being educated at Aalborg University, experience, R&D job, and mobility rate have no significant effect in the regression Models 2a-b. As a result it is not possible to confirm Hypothesis 4. However, 28% of the engineers have not changed work place, while 26% have changed once. The remaining 46% have changed multiple times, but it is apparently not the job change that automatically creates informal contacts with the former colleagues. The dummy variables for whom the engineers are in contact with (former colleagues, former classmates or private friends) are also significant and positive in both models. The likelihood ratios for Models 2a-b are significant and the concordant ratios are 73.1% and 66.4%. The VIF statistics reveal no sign of multicollinearity.

The regressions in Models 2c-d for university-industry contacts reveal that the contact dummy variables are significant and positive. The variables for experience, R&D job function, and mobility have no influence on the likelihood of acquiring knowledge. Thus, it is not possible to confirm Hypothesis 1 that employees with a higher absorptive capacity are more likely to acquire knowledge. The experience of formally working together with university researchers on projects significantly increases the likelihood of acquiring knowledge in both models. Thus it is possible to confirm Hypothesis 2 that engineers who have participated in formal projects are more likely to acquire knowledge through informal contacts. The importance of being educated at the local university seems also to play an important role in establishing informal contacts. These engineers are almost three times as likely to acquire knowledge from university sources compared to their colleagues. However, Hypothesis 7 can only be partly confirmed because the engineers educated at Aalborg University only have a significant and strong positive effect for university-industry contacts. The locally educated engineers or engineers previously involved in formal projects seem to maintain their contact with university researchers despite the negative effect of experience found in Model 1b. The likelihood ratios are again highly significant and positive, and the predictive power of the models is also high (82-6%). The VIF statistics show no signs of multicollinearity.

INSERT TABLE 5

The interfirm social networks and the university-industry social networks seem to have many structural similarities. A common sociological feature is the importance of formal projects in the past. The engineers get to know other engineers employed in other firms when they are working on inter-organisational projects. The experience of working together seems to build trust and increase the likelihood of future exchange of knowledge, especially for university-industry links. This variable is positive and significant in all the regression models, which confirm Hypothesis 2. This finding is consistent with the arguments of Lissoni (2001) and Fleming and Frenken (2007). Experience as a proxy for absorptive capacity is, surprisingly, not important for having informal contacts or acquiring knowledge, except in Model 1b where it is negative. The negative effect of experience could be an effect of the high employment growth in the cluster. The large share of respondents with a relative short work experience might still keep in contact with former classmates and still use them as a source of knowledge. Contact with former colleagues is positive, but mobility has no significant effect on having interfirm informal contacts. However, there are also differences between these two types of contacts. Approximately half of the sample is educated at the local university. This background is important for acquiring knowledge from the university through informal channels. In line with other studies (Breschi and Lissoni, 2001; Fleming and Frenken, 2007), the empirical models show that the university is a platform for the creation of informal contacts. However, this effect is only significant for university-industry contacts.

4.3 Factors that characterise an engineer who acquires knowledge of high-value

Some of the respondents report that they receive knowledge of high-value from their informal contacts. The likelihood for this is investigated using a cumulative value-ordered probit regression model. The results of Models 3a-d are shown in Table 6. The results are quite similar to the factors that influence the likelihood of acquiring knowledge in Models 2a-d. Participation in a formal project increases the likelihood of acquiring valuable knowledge for interfirm and university-industry contacts. The contact dummy variables also remain significant and positive except for university contacts, where contact with former colleagues is not significant. Contact with former colleagues has the highest impact for interfirm contacts, while contact with former classmates is more important for university-industry contacts. Experience and mobility have no significant effects for interfirm networks. Engineers who answer R&D as main job function have a significant and negative effect for interfirm contacts. The R&D engineers are working on the firm's technological frontier. The problems they face are firm-specific and the new knowledge from their research is often tacit. As a result, the knowledge they acquire is less likely to be of high value in their own work. In addition the R&D engineers are not likely to discuss their work in details with engineers working in competing firms because they are loyal to their firm (Breschi and Lissoni, 2001). For university-industry contacts, the likelihood of obtaining high-value knowledge is not significantly increased with experience, having R&D as main function or having a higher rate of mobility.

The education institution variable is significant and positive for both interfirm and university-industry contacts. For the university-industry contacts, this result supports Hypothesis 7 and supplements the findings from Models 1c-d and Models 2c-d. Aalborg University graduates are more likely to benefit from valuable knowledge acquired through informal contacts with university researchers. These engineers might have a wider extent of social networks and more easily gain from it. The local educational background also proves to be an advantage when sourcing high-value knowledge through interfirm contacts. This point towards that many informal contacts are created at the university and then continued after graduation. All models are significant, have high concordant ratios, and the VIF statistics do not show signs of multicollinearity.

INSERT TABLE 6

5 Discussion

The informal networks between engineers working in different firms in the wireless communications cluster are frequent. However, they are also exclusive and created over time by individuals (Lissoni, 2001; Saxenian, 2006; Giuliani, 2007). Engineers working in a cluster do not automatically have informal contacts. 22 % of the engineers in the sample respond that they do not have an informal contact with engineers working in other firms or at the university. The engineers in the cluster are working within the same knowledge domain, but there are several distributed communities of practice (Wenger et al., 2002). Some features of the engineers make it more likely that they have informal contacts and receive knowledge. The regressions reveal that engineers who previously have participated in formal projects and are educated at the local university are more likely to have informal contacts and acquire knowledge.

This study also shows that knowledge does not simply flow between a university and the local industry. The social networks between engineers in private firms and university researchers are also exclusive and are created over time by individuals. 29% of the engineers in the cluster have an informal contact with university researchers. The university appears to be a platform for the creation of informal networks. The regression analyses reveal that engineers from Aalborg University and engineers who have participated in formal projects with university researchers are more likely to have informal contacts and acquire knowledge through these contacts. The results show that informal contacts between employees in different firms are more frequent than university-industry informal contacts in the wireless communications cluster. Thus, it is possible to confirm Hypothesis 5 that interfirm informal contacts are more frequent than university-industry informal contacts. Likewise, 31% of the respondents acquire knowledge from inter-firm contacts and only 13% through university contacts. Hypothesis 6 states that an employee's likelihood of acquiring knowledge through interfirm informal contacts is higher than for university-industry informal contacts. This was expected because the university is more engaged in basic research compared to applied firm research and knowledge is transferred more easily between engineers working in similar jobs. There is a clear difference in absolute numbers, but the relative shares are more similar. If the results are normalised for the number of respondents who have an informal contact, the average shares of respondents who acquire knowledge are not significantly different because the interfirm contacts are more frequent. As a result it is not possible to confirm Hypothesis 6.

Lissoni (2001) found that 36% of a sample of 200 engineers from the Brescia cluster had a relationship of some kind with engineers in other firms. 63% of the engineers with informal contacts were involved in technical discussion (18% of the sample). However, only 15% of the engineers talked about current projects or gave/received specific suggestions (4.5% of total sample). Thus the overall levels of informal contacts and knowledge sharing are higher in the wireless communications cluster around Aalborg. This can be an effect of the fast changing high-technology features of the industry combined with the close geographical and technological boundaries of the cluster. Furthermore, half of the engineers are educated from Aalborg University.

Experience is used as a proxy for absorptive capacity in the regressions. However, it has no significant impact on the likelihood of having interfirm informal contacts. It has a weak and negative effect on the likelihood of having an informal contact with university researchers with a 7% decrease in the odds for each extra year of experience. Hypothesis 1 states that employees with a higher absorptive capacity are more likely to acquire knowledge through informal contacts following the arguments of Cohen and Levinthal (1990) and Giuliani (2007). Thus experienced engineers should have more contacts and be more able to acquire valuable knowledge than inexperienced engineers. However, work experience is not significant in any of the interfirm or university-industry models for acquiring knowledge and receiving high-value knowledge. Experience might be a poor proxy for absorptive capacity in a high-technology industry with highly educated technical personnel, because it does not measure technical experience within various technology sub-groups.

The analyses of which factors affect the likelihood of having an informal contact and acquiring knowledge reveal differences between the two types of contacts and some unexpected results.

Mobility is expected to have a positive effect on the likelihood of having informal contacts and acquiring knowledge through informal contacts (Hypothesis 3 and 4). The results of the regressions impose some uncertainty to the role of employee mobility in creating informal contacts. The dummy variables on contact with former employees are highly significant in the models on acquiring knowledge, but the mobility rate is insignificant in every regression. Changing jobs increase the number of people the engineer knows in the cluster. If the technological distance between the current job and the former job is close it should create opportunities for keeping informal contact with the old colleagues. However, the distinction between firm-specific and industry-specific knowledge combined with formal organisational communication structures might explain why old colleagues not necessarily become an important informal source of knowledge[3]. Allen's (1984) studies of communication patterns in organisations show that employment in a company does not automatically create communication between employees. In addition a connection can easily be broken after a job change. This depends also on the culture regarding mobility in the cluster (Saxenian, 1994). It should also be noted that mobility is measured as number of job changes within the cluster divided by experience. Having a high mobility rate could make the engineer seem less reliable and the new colleagues might not want to

[3] Other indicators of mobility such as number of job changes, number of different workplaces, above/under average mobility, and a mobility dummy were also used in regressions, but proved to be insignificant

build close work relationships with a person who is known for frequent job changes. The respondents and their contacts are anonymous so it is not possible to explore the importance of mobility in depth. Previous joint work experience could potentially be more important than mobility in creating informal contacts that are used for acquiring knowledge. Then it is not the change of jobs that automatically creates an informal channel for future knowledge flows, but the experience of working together on the same project. This is in line with the arguments of Cross et al. (2002).

Working together across firm boundaries on formal projects seems to create relationships that last longer than the projects. The logistic regressions in Models 1-3 tested Hypothesis 2 that employees previously involved in formal projects with employees in other firms or university in the cluster have a higher likelihood of having informal contacts and acquiring knowledge. The results show a strong effect of formal projects, where engineers previously involved in formal projects with other firms had a higher likelihood of having informal contacts and acquiring useful knowledge through informal contacts. This result reflects the claims made by Lissoni (2001) that social networks can be created across firm boundaries as a result of formal cooperation between firms. Participation in formal projects has even a larger effect for university-industry contacts. Likewise, Meyer-Krahmer and Schmoch (1998) argues that university researchers like to keep in contact with employees in firms on the technological forefront to obtain new knowledge. The motives for an engineer to keep in contact with engineers working in another firm or university can also be to keep opportunities for participation in future projects or for future job opportunities (Granovetter, 1973). Formal projects seem to be rather frequent in the cluster. 20% of the respondents have participated in projects with other firms and 13% have participated in projects with the university. This is also caused by the high-tech character of the cluster and the existence of specialised research competences at the university. Firms in high-tech sectors are well-known to cooperate with universities more often than other firms.

So far, the factors explaining the informal contacts and likelihood of acquiring knowledge have been quite similar for interfirm and university-industry contacts. However, the educational institution matters for the creation of informal contacts with university researchers. Hypothesis 7 claims that employees educated at the local university are more likely to acquire knowledge through informal contacts. The results reveal that being educated at Aalborg University has a positive and significant effect on the likelihood of having interfirm informal contacts, but is has no effect on the likelihood of acquiring knowledge through these contacts. However, having an educational background from Aalborg University was positive and significant in the university-industry regressions. Engineers who are educated from the local university are more likely to have informal contacts with researchers at the university than engineers from other non-local universities. Likewise, the locally educated engineers are more likely to acquire knowledge and also to obtain more valuable knowledge. These might have gained a better knowledge of “who knows what” at the university or have lower barriers for contacting university researchers. Another explanation is in line with the arguments of Fleming and Frenken (2007) that many engineers have formed the social networks when they were students and simply keep in contact with former classmates.

6 Conclusion

The idea of the paper was to go beyond the assumption that university research simply spills over to firms located nearby. The purpose was to investigate the extent of engineers having informal contacts with university researchers and acquiring knowledge they could use in their own job through this contact. These results are compared to results for informal contacts between engineers in different firms. An additional purpose was to analyse and compare the factors that characterise engineers who have informal contacts and acquire knowledge.

This study contributes to the critique of localised knowledge spillovers. The informal contacts between employees working in different firms are frequent (71%), while the informal contact with university researchers is less frequent (29%). There are also engineers who do not have an informal contact with engineers in other firms or university researchers (22%). Thus, the informal networks are exclusive and the cluster has several distributed communities of practice. In addition, most of the informal contacts (55-60%) are not used to acquire knowledge. There are no automatic knowledge spillovers through informal contacts for engineers in the cluster. Knowledge is diffused in informal networks that are built over time by individuals who have previous experience from participation in joint projects or know each other from the local university. The social network between employees in firms and university researchers are also likely to consist of smaller epistemic communities that do not include all employees of the local industry.

This result shows that knowledge is diffused through informal contacts. Most engineers have informal contacts with employees working in other firms and many actually obtain useful knowledge from these sources. Some engineers also acquire knowledge they consider being of high-value in their own job. Many engineers have informal contacts with university researchers and some acquire knowledge from them. However, the university-industry contacts are less frequent. Only 29% of the respondents have an informal contact with university employees compared to 75% for interfirm contacts. Likewise, a lower share of the engineers acquires knowledge from informal university contacts. One explanation is the large difference between the number of employees and the number of university researchers in the cluster. Another explanation relates to the difference in job functions and importance of various types of knowledge. When an engineer faces a problem, he/she is more likely to know and contact an engineer working in a different firm in the industry than a university researcher to get help to solve the particular problem. Questions related to a particular work routine in a company can only be answered by employees with similar work routines and these are more likely to be employed in another firm than at the university. However, the share of engineers who acquire knowledge as a proportion of the engineers who have an interfirm informal contact is not significantly different from the university-industry contacts.

The profile of an engineer who acquires knowledge through university informal contacts is an engineer who is educated at the local university, has previously participated in formal projects with the university, and is in contact with former classmates at the university. Some of these sociological factors are also a part of the factors that describe an engineer who acquires knowledge from interfirm informal contacts. However, there are also some differences. The educational background is important for creating informal contacts with the university researchers and obtaining knowledge from them, while it appears to be unimportant for interfirm informal contacts.

Engineers have to know and trust each other and have a common coding scheme before they share knowledge through informal contacts. Therefore, one of the common mechanisms in creating informal contacts is joint work experience, such as working together on a formal project across firm boundaries or maintaining relationships with former colleagues or classmates. These long-term relationships are also more likely to be channels of knowledge sharing. However, the missing effect of mobility shows that just because people have worked in the same company or studied at the same university, it does not automatically leads to the formation of an informal contact between them. Employees obviously do not know all other employees in the firm and it is not certain that the contact between two former employees will persist after a job change. The informal contacts evolve over time, but they are built by individuals in a selective manner and they are influenced by the individuals' engagement, interactions, and experience.

This study has certain limitations. It shows that social networks and informal contacts are used as channels for diffusing knowledge between employees working in different firms and university researchers in a cluster of wireless communications technology firms around Aalborg Denmark. A high-technology cluster has different properties than a cluster consisting of traditional manufacturing firms because the technology is changing faster and the R&D engineers are the most important factor of production for the wireless communications firms. The respondents are anonymous, which made it impossible to create a social network analysis of informal contacts and to gain a more accurate picture of the extent of the social network. In addition, there is no time dimension that could show how these networks evolve and change over time. Furthermore, it is not possible to estimate the quantity of knowledge flowing through informal contacts and its importance relative to other sources.

Future studies should address some of these limitations and try an include performance indicators to investigate the effect of knowledge flows through social networks and the evolution of these. In addition, it is necessary to include both employees in firms and university researchers in these studies and also to include questions regarding informal contacts with engineers working in firms outside the cluster.

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Table 1 Distribution of observations across the categorical variables

	Interfirm			University-industry		
Dependent variables	Number of observations	Percentage of observations	Percentage of total	Number of observations	Percentage of observations	Percentage of total
Informal contact			(n=346)			(n=346)
No	86	24.86	24.86	246	71.10	71.10
Yes	260	75.14	75.14	100	28.90	28.90
Knowledge acquisition						
No	153	58.85	69.08	55	55.00	86.99
Yes	107	41.15	30.92	45	45.00	13.01
Value of knowledge						
No knowledge			69.94			87.57
Low	38	35.51	10.98	12	26.67	3.47
Medium	57	53.27	16.47	24	53.33	6.94
High	9	8.41	2.60	7	15.56	2.02
Independent variables						
Participated in formal projects						
No	277	80.06	80.06	300	86.71	86.71
Yes	69	19.94	19.94	46	13.29	13.29
Educational institution						
Local university	180	52.02	52.02	180	52.02	52.02
Other institutions	166	47.98	47.98	166	47.98	47.98
R&D as main job function						
No	86	24.86	24.86	86	24.86	24.86
Yes	260	75.14	75.14	260	75.14	75.14
Contact with former colleagues						
No	89	34.23	50.58	77	77.00	93.35
Yes	171	65.77	49.42	23	23.00	6.65
Contact with former classmates						
No	130	50.00	62.43	54	54.00	86.71
Yes	130	50.00	37.57	46	46.00	13.29
Contact with private friends (within local industry/university)						
No	137	52.69	64.45	58	58.00	87.86
Yes	123	47.31	35.55	42	42.00	12.14

Table 2 Types of knowledge acquired through informal contacts

	Interfirm		University-industry	
Type of knowledge	Number of observations	Percentage of observations (n=107)	Number of observations	Percentage of observations (n=45)
General knowledge	85	79.4	35	77.8
Technical knowledge on standard equipment	19	17.8	2	4.4
Technical knowledge on new products	33	30.8	7	15.6
Other	8	7.4	8	17.8

Note: The respondents could mention several types.

Table 3 Descriptive statistics and correlation matrix

	Interfirm contacts	Mean	S.D.	Min.	Max.	1	2	3	4	5	6	7	8	9	10
1	Informal contact	0.75	0.43	0.00	1.00	1.00									
2	Knowledge acquisition	0.31	0.46	0.00	1.00	**0.38**	1.00								
3	Value of knowledge	0.52	0.86	0.00	3.00	**0.35**	**0.90**	1.00							
4	Participated in formal projects	0.20	0.40	0.00	1.00	**0.14**	**0.20**	**0.21**	1.00						
5	Educational institution	0.52	0.50	0.00	1.00	**0.20**	**0.13**	**0.16**	0.09	1.00					
6	Experience	8.60	6.38	1.00	34.00	-0.03	0.10	**0.15**	**0.26**	**-0.12**	1.00				
7	R&D job	0.75	0.43	0.00	1.00	0.03	**-0.11**	**-0.14**	-0.08	-0.04	**-0.29**	1.00			
8	Mobility rate	0.23	0.37	0.00	5.00	-0.09	-0.07	-0.06	0.00	**-0.15**	-0.04	-0.06	1.00		
9	Contact with former colleagues	0.49	0.50	0.00	1.00	**0.57**	**0.23**	**0.24**	**0.19**	-0.02	**0.26**	-0.07	0.04	1.00	
10	Contact with former classmates	0.38	0.49	0.00	1.00	**0.45**	**0.17**	**0.12**	0.03	**0.34**	**-0.35**	**0.14**	-0.07	0.03	1.00
11	Contact with private friends	0.36	0.48	0.00	1.00	**0.43**	**0.20**	**0.16**	0.07	0.04	-0.05	-0.08	0.00	**0.22**	**0.21**

	University-industry contacts	Mean	S.D.	Min.	Max.	1	2	3	4	5	6	7	8	9	10
1	Informal contact	0.29	0.45	0.00	1.00	1.00									
2	Knowledge acquisition	0.13	0.34	0.00	1.00	**0.61**	1.00								
3	Value of knowledge	0.23	0.66	0.00	3.00	**0.55**	**0.91**	1.00							
4	Participated in formal projects	0.13	0.34	0.00	1.00	**0.16**	**0.25**	**0.29**	1.00						
5	Educational institution	0.52	0.50	0.00	1.00	**0.34**	**0.25**	**0.28**	**0.12**	1.00					
6	Experience	8.60	6.38	1.00	34.00	**-0.16**	0.01	0.06	**0.14**	**-0.12**	1.00				
7	R&D job	0.75	0.43	0.00	1.00	0.01	-0.10	**-0.12**	**-0.11**	-0.04	**-0.29**	1.00			
8	Mobility rate	0.23	0.37	0.00	5.00	-0.07	-0.07	-0.06	-0.04	**-0.15**	-0.04	-0.06	1.00		
9	Contact with former colleagues	0.07	0.25	0.00	1.00	**0.42**	**0.31**	**0.29**	**0.20**	**0.19**	0.02	-0.03	-0.02	1.00	
10	Contact with former classmates	0.13	0.34	0.00	1.00	**0.61**	**0.38**	**0.31**	0.10	**0.31**	**-0.19**	0.03	-0.09	**0.20**	1.00
11	Contact with private friends	0.12	0.33	0.00	1.00	**0.58**	**0.33**	**0.31**	**0.12**	**0.14**	0.02	-0.05	0.02	**0.29**	**0.19**

Note: Numbers in bold have associated p-values lower than 0.05

Table 4 Results of the logistic regression for informal contact

	Model 1a: Interfirm				**Model 1b: University–industry**			
Variables	Parameter Estimate	S.D.	Odds Ratio	Marginal effect	Parameter Estimate	S.D.	Odds Ratio	Marginal effect
Intercept	1.60***	0.327			-0.14	0.324		
Participated in formal projects (vs. no)	0.47**	0.199	2.57	0.088	0.50***	0.180	2.74	0.103
Educational institution (AAU vs. other)	0.42***	0.135	2.33	0.079	0.78***	0.143	4.77	0.160
Experience	-0.01	0.021	0.99	-0.002	-0.07***	0.025	0.93	-0.014
R&D job (vs. other)	0.09	0.154	1.20	0.017	-0.01	0.159	0.97	-0.003
Mobility rate	-0.32	0.329	0.73	-0.059	-0.14	0.407	0.87	-0.028
Observations	346				346			
Concordant	64.9				75.2			
Likelihood ratio	21.39***				57.40***			

Note: *: P<0.1, **: P<0.05, ***: P<0.01. The marginal effects are calculated at the mean of the dependent variable.

Table 5 Results of the logistic regression for acquiring knowledge

	Interfirm						University-industry					
	Model 2a		Model 2b				Model 2c		Model 2d			
Variables	Parameter Estimate	S.D.	Parameter Estimate	S.D.	Odds Ratio	Marginal effect	Parameter Estimate	S.D.	Parameter Estimate	S.D.	Odds Ratio	Marginal effect
Intercept	-0.50	0.323	-0.49***	0.150			-0.19	0.531	-0.35	0.357		
Participated in formal projects (vs. no)	0.34**	0.154	0.42***	0.146	2.30	0.089	0.63***	0.227	0.67**	0.222	3.83	0.076
Educational institution (AAU vs. other)	0.16	0.137					0.47**	0.240	0.51**	0.237	2.75	0.057
Experience	0.03	0.024					0.01	0.034				
R&D job (vs. other)	-0.21	0.150					-0.24	0.226				
Mobility rate	-0.84	0.587					-0.73	0.935				
Contact with former colleagues (vs. no)	0.39***	0.137	0.40***	0.128	2.24	0.086	0.58**	0.283	0.56**	0.278	3.09	0.064
Contact with former classmates (vs. no)	0.35**	0.148	0.32**	0.127	1.89	0.068	0.88***	0.227	0.85***	0.214	5.49	0.096
Contact with private friends (vs. no)	0.30**	0.131	0.29**	0.128	1.79	0.062	0.74***	0.228	0.75***	0.223	4.48	0.085
Observations	346		346				346		346			
Concordant	73.1		66.4				86.3		82.6			
Likelihood ratio	49.39***		40.24***				79.75***		77.53***			

Note: *: P<0.1, **: P<0.05, ***: P<0.01. The marginal effects are calculated at the mean of the dependent variable.

Table 6 Results of the cumulative value-ordered probit regressions for high-value

	Interfirm				University-industry			
	Model 3a		Model 3b		Model 3c		Model 3d	
Variables	Parameter Estimate	S.D.	Parameter Estimate	S.D.	Parameter Estimate	S.D.	Parameter Estimate	S.D.
Intercept 3	-2.03***	0.226	-1.90***	0.162	-1.71***	0.311	-1.70***	0.231
Intercept 2	-0.83***	0.185	-0.71***	0.103	-0.77***	0.279	-0.78***	0.188
Intercept 1	-0.43**	0.182	-0.32***	0.098	-0.49*	0.276	-0.51***	0.185
Participated in formal projects (vs. no)	0.17*	0.086	0.20**	0.083	0.35***	0.117	0.38***	0.115
Educational institution (AAU vs. other)	0.17**	0.077	0.18**	0.076	0.41***	0.128	0.42***	0.126
Experience	0.02	0.013			0.01	0.017		
R&D job (vs. other)	-0.15*	0.083	-0.17**	0.080	-0.12	0.113		
Mobility rate	-0.43	0.320			-0.45	0.502		
Contact with former colleagues (vs. no)	0.25***	0.077	0.27***	0.074	0.23	0.149	0.23	0.147
Contact with former classmates (vs. no)	0.17**	0.083	0.13	0.078	0.34***	0.120	0.33***	0.114
Contact with private friends (vs. no)	0.14*	0.074	0.13*	0.074	0.34***	0.123	0.36***	0.119
Observations	346		346		346		346	
Concordant	71.6		69.7		85.7		81.6	
Likelihood ratio	54.15***		49.36***		79.25***		76.21***	

Note: *: P<0.1, **: P<0.05, ***: P<0.01.