Knowledge-sourcing of R&D workers in different job positions: contextualising external personal knowledge networks

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Abstract

This paper systematically examines the role of external personal knowledge networks vis-à-vis alternative sources of work-related knowledge. Specific hypotheses on whether the importance of external personal networks vary for job positions, knowledge functions and sources of competitiveness are examined. The study is based on a survey and interviews with 105 R&D workers in 46 Information Technology (IT) firms in the Greater Cambridge Region (UK).

The results show that alternative sources of knowledge are considerably more important than external personal networks. Specifically, the results confirm the hypothesis that the lower the job position, the less important are external personal networks. The most frequent type of knowledge that is uniquely available through personal networks concerns business knowledge of senior managers rather than technological knowledge. Furthermore, the analysis supports the view that external personal networks are most important for exploratory keeping up-to-date than for problem solving. Finally, the paper shows that external personal networks are more important for firms whose competitiveness is primarily driven by being cutting-edge in technology.

Overall, the results suggest that academic theorising and R&D management/policy on external personal networks needs to be more context-sensitive and would benefit from differentiating between job positions, knowledge functions and types of firm competitiveness.

Keywords: knowledge sourcing; personal networks; knowledge networks; inter-organizational networks; clusters; R&D

1. Introduction

The acquisition of knowledge as a key resource has been identified as a key topic for innovative firms and R&D policies. Importantly, since technological fields have become increasingly dynamic and complex, individual R&D workers face challenges in terms of sourcing relevant knowledge, which is often distributed across organizations and individuals (e.g. Galunic and Rodan, 1998; Kogut and Zander, 1992). It has often been argued that progressively, the distributed nature of networked R&D makes external sourcing of knowledge outside of one's own organisation important (Chesbrough, 2003; Howells, 2008; Howells et al., 2003; Huggins, 2010; Leonard-Barton, 1995; Macpherson and Holt, 2007; Nooteboom, 2004). Absorptive capacity, the ability to recognise, absorb and utilise outside sources of knowledge, has been identified as critical for organisations (Cohen and Levinthal, 1990). For instance, internal R&D activities enable knowledge networks with external scientists, which provide search benefits for innovation (Fabrizio, 2009), and it has often been pointed out that personal networks are critical.

However, the literature has often uncritically accepted, or even celebrated, the importance of external (inter-organisational) personal knowledge networks without empirically examining their exact role (Sunley, 2008). Although a few studies, particularly on small business and entrepreneurship, have already shed light on the functioning as well as the

limitations of external personal networks (e.g. Edelman et al., 2004; Lechner and Dowling, 2003; Zhang, 2010), more critical empirical research is needed (i) to understand the contexts in which external personal knowledge networks are important/unimportant and (ii) to contextualise them vis-à-vis alternative sources of knowledge. Specifically, the question whether the importance of personal knowledge networks varies according to certain contexts such as job positions, certain knowledge functions and types of firms has been underexplored. Yet, an understanding of these contexts would help targeting networking initiatives in R&D management and policy.

This paper aims to address these issues by systematically examining the relative significance of external personal knowledge networks for R&D workers in the Cambridge IT (information technology) Cluster. The results are based on a survey and interviews with 105 R&D workers—including technology managers and managing directors in micro businesses if they are actively involved in R&D—in 46 hardware and software companies in the Greater Cambridge Region.[1] The paper examines the importance of external personal networks vis-à-vis alternative sources of knowledge including the kinds of knowledge that are uniquely available through personal networks. Importantly, the paper tests whether the role of personal knowledge networks varies for different job positions, knowledge functions and the sources of competitiveness.

The results contribute to a more sophisticated understanding of the contexts in which external personal knowledge networks are significant or unimportant. This contributes to a more nuanced contingency-theoretic perspective on inter-organisational personal knowledge networks for R&D workers, which can facilitate more targeted networking initiatives in R&D management and policy.

[1] The diverse empirical material of this study has been used for other publications but on different topic areas. Whereas Huber (2012a) focuses on the advantages of being located in the Cluster, Huber (forthcoming) discusses the role of different types of proximity for personal knowledge networks. Furthermore, Huber (2012b) elaborates on the dynamic mechanisms of formation, maintenance and knowledge interactions.

The remainder of the paper is structured as follows. First, the existing literature is critically discussed, gaps are highlighted and hypotheses are developed in section 2. Section 3 outlines the material and methodology of the study. Afterwards, section 4 presents and discusses the results. Finally, section 5 concludes and reflects on the implications and limitations.

2. Sourcing knowledge: personal networks and alternative sources

Section 2.1. outlines that much of the diverse literature on innovative, R&D intensive firms highlights the importance of external personal knowledge networks and key concepts are introduced. Afterwards, section 2.2. identifies gaps in the literature and develops research hypotheses.

2.1. External personal knowledge networks

Inspired by the work of Lundvall (1992) on *innovation* systems, much of the literature on innovative firms has highlighted the vital role of interactive learning between organisations (Pittaway et al., 2004). For instance, in the software industry, it has been widely argued that knowledge networks, alliances and partnerships are essential (Grabher, 2004; Jordan and Segelod, 2006; Segelod and Jordan, 2004; Trippl et al., 2009). In the light of these thoughts, 'open innovation' has been proposed as a strategy of deliberately allowing inflows and outflows of knowledge across company boundaries to enhance innovation capability (Asakawa et al., 2010; Chesbrough, 2003). In general, it has been often argued that firms

without external knowledge linkages face severe disadvantages in terms of innovativeness and commercial success (Enkel et al., 2009).

Such knowledge networks can represent *formal* arrangements such as official alliances, subcontracting, co-operative agreements, joint ventures, R&D collaboration or licensing (see e.g. Krätke, 2010; Lane and Probert, 2007; Powell et al., 1996). Yet, importantly for this article, much of the literature on learning and innovation has also stressed the importance of *informal* inter-organisational networks beyond officially planned collaborations and formal role structures. Individuals often know each other and interact beyond official business duties, which can lead to informal personal networks being an often invisible, but powerful, intangible infrastructure (e.g. Allen, 1977; Cross and Parker, 2004; Krackhardt and Hanson, 1993; Kratzer et al., 2008; Kreiner and Schultz, 1993; Rost, 2011). For instance, Weck and Blomqvist (2008) suggest that informal inter-organisational relationships are the main source of external knowledge for patent inventors rather than formal contractual arrangements.

The importance of external knowledge networks has been highlighted by different strands of the literature.

In the *open innovation* literature, according to the clarifying conceptual typology by Dahlander and Gann (2010), accessing external knowledge through personal knowledge networks—the topic of this paper—concerns non-pecuniary inbound open innovation.

In the literature on *innovative regions*, nearly all recent territorial innovation models have highlighted that networks between firms and organisations are critical for innovation and regional economic development (Boggs and Rantisi, 2003; Grabher, 2006). Knowledge relationships with (local or non-local) external partners are considered to be essential for innovative geographical clusters (Belussi et al., 2010; Cooke et al., 1997; Eisingerich et al., 2010; Huber, 2009). It has been argued that informal contacts across companies, often driven by inter-firm labour mobility, can lead to important inter-organisational knowledge linkages

(e.g. Keeble, 2000; Mason et al., 2004; Saxenian, 1996). Moreover, the collective, and often informal, aspect of knowledge production in regional economies has been emphasised with reference to the notions of communities of practice and epistemic communities (Amin and Cohendet, 2004; Benner, 2003; Brown and Duguid, 2000; Håkanson, 2005). As one of the most sophisticated empirical studies, Dahl and Pedersen (2004, 2005) reveal that engineers in the wireless communication cluster around Aalborg have frequent contacts with each other (usually as former colleagues or classmates), which often leads to the receipt of useful work-related knowledge.

Also the *small business and entrepreneurship* literature has highlighted the importance of internal and external personal networks (Anderson et al., 2007; Bowey and Easton, 2007; Casson and Della Giusta, 2007; Chen and Wang, 2008; Collinson and Gregson, 2003; Greve and Salaff, 2003; Johannisson, 1998; Lechner and Dowling, 2003). External relationships can help entrepreneurs to source complementary knowledge as illustrated, for instance, by Macpherson et al. (2004).

Moreover, in terms of *network policies*, Huggins (2001) argued that policy initiatives which focus on informal networks work better in creating inter-organisational relationships than formal networks initiatives. Similarly, Nishimura and Okamuro (2011) argue that for cluster policies, indirect networking/coordination support has a stronger impact on firm performance than direct R&D support.

To clarify the terminology, in this paper the term *external personal knowledge relationships* refers to knowledge interactions between individuals in different organisations, who know each other personally and interact beyond official work duties. Such relationships can be informal, but they can also be embedded in formal relationships as long as they involve personal acquaintance and knowledge interactions beyond formally prescribed roles. Chatting with strangers (e.g. in trade fairs) and interactions in online discussion forums do not

count as personal acquaintance in this article and are therefore not categorised as personal knowledge networks. *Personal knowledge networks* refers to a set of actors and their knowledge relationships, whereas personal knowledge contact refers to the person which whom somebody has a knowledge relationships with. The qualitative strength of personal relationships can have implications for knowledge sourcing, and there can be a trade-off between maintaining a high number of weak ties versus few strong ties (e.g. Eisingerich et al., 2009; Granovetter, 1973; Hansen, 1999; Krackhardt, 1992). However, this is not the focus of this article. The issue of tie strength (sometimes also called social proximity) and interactions with other types of proximity are discussed in Huber (forthcoming).

2.2. Gaps in the literature and research hypotheses

Despite the considerable advances in the debate, there seems to be the general danger in some of the above-mentioned literature that relational research can be confirmatory and empirically immune: "there is little dialogue between theory and data, little real possibility of falsification but, rather, a continual mirroring and reinforcement of ideas" (Sunley, 2008). Within the context of this paper, the risk is that research only looks for examples of external personal knowledge networks that can be found somewhere without contextualising how widespread or important these examples are. In particular, to avoid this danger, it seems essential to investigate the role of personal networks vis-à-vis alternative sources of knowledge.

In the innovation literature, a few studies have already warned us that the heavy focus on inter-firm networks might be exaggerated by pointing out that intra-firm knowledge sources and market relations can often be sufficient for innovation, not only for large firms but also for SMEs (e.g. Freel, 2003; Frenz and Ietto-Gillies, 2009; Huggins and Johnston, 2009;

Romijn and Albaladejo, 2002; Vega-Jurado et al., 2008; Weterings and Boschma, 2009). Also, Clifton et al. (2010) highlight the complexity of the relationship between networks and innovation/growth for SMEs in the UK; they find that informal relationships are negatively associated with innovation but positively related to growth outcomes. Furthermore, Huggins (2001) shows that public policies that aim to facilitate inter-firm networks can have only very limited effects on interaction and firm performance. Although these statistical analyses are important contributions, they involve the following limitation: these studies examine the relevance of knowledge networks at the firm-level and not at the individual level. Yet, the personal level is where the mechanisms of learning and knowledge flows actually take place (Malmberg and Power, 2005), even if they are embedded in formal networks.

An important exception is the recent survey by Ibrahim et al. (2009), which suggest that for inventors in the US telecommunication industry, corporate sources of knowledge are consistently more important than outside sources in the local environment. Moreover, the survey by Isaksen (2004) with senior managers shows that for software consultancies in Oslo, internal know-how and other resources within the firm are rated most significant for their competitiveness. Also Waters and Lawton Smith's (2008) study on engineers, physicists and chemists in Oxfordshire an Cambridgeshire reveals that the importance of local networks should not be overstated, since a significant number does not have any networks.

Moreover, the small firm and entrepreneurship literature has highlighted more specific dimensions of why the benefits of external personal networks can be limited. Lechner and Dowling (2003) have shown that IT firms need a specific mix of networks in different development phases; and the importance of social networks decreases with the firm's development. Also, social networks at founding have no direct effect on time-to-break even and a negative effect on sales in the first years (Lechner et al., 2006). Furthermore, a few contributions have revealed qualitative reasons why the use of personal relationships for

knowledge sourcing can be problematic. For instance, strong personal bonds can create exclusive barriers that hinder the flow of new information (Edelman et al., 2004; Jack, 2005). Furthermore, as discussed in the study of entrepreneurs in Singapore by Zhang (2010), using personal relationships for acquiring resources can also involve complications such as limited access to new information and tensions between work and private life. However, overall, as Zhang (2010) stresses, the limitations and negative effects of personal networks have not received sufficient attention. Similarly, the reviews by Hoang and Antoncic (2003) as well as by Witt (2004) highlight that more empirical research is needed to understand potential problems of using networks for entrepreneurial firms. For instance, knowledge sourcing might vary significantly for different contexts such as job positions, knowledge functions or types of firms, which has not been thoroughly investigated.

What is more, the relative significance of various sources of knowledge for R&D and innovation practices is an underexplored topic (Trippl et al., 2009). Discussing the limitations of their own cutting-edge contribution, Dahl and Pedersen (2004) note themselves (p. 1685) that future research should compare the value of different knowledge channels, which can illuminate the role of personal networks. An important exception is the study by Trippl et al. (2009), which examines a variety of formal and informal knowledge channels. In particular, they demonstrate that in the Vienna software industry informal networks and what they call spillovers (reading literature and patent specifications, monitoring competitors, recruiting specialists, and participating in trade fairs and conferences) are most important. However, this important study still leaves certain questions unanswered: first, external sources are not contrasted with internal sources (in particular tapping into the knowledge of colleagues within the firm). Second, the paper does not examine the types of work (e.g. management, problem solving, exploration) for which those sources are used. Third, the composition of their respondents in terms of job positions remains intransparent; the focus on surveying

'firms'/'key personnel' seems to be on higher managerial job positions, which leaves out the experience of non-managerial engineers. The significance of external personal knowledge relationships could vary significantly according to such contextual factors, which has not been investigated by the literature.

This paper addresses the above-mentioned issues by examining the importance of external personal networks vis-à-vis alternative sources of work-related knowledge for individual R&D workers in different job positions. Within this context, the paper investigates the unexplored, but important, question which type of knowledge can be uniquely accessed through personal networks and no other source. Furthermore, it addresses the lack of contingency-theoretic research on contextual factors by examining the role of external personal networks for different knowledge functions, job positions in R&D and sources of firm competitiveness. The subsequent sections elaborate on these issues and develop research hypotheses.

2.2.1. Examining job positions

The existing literature on learning and networks of innovative firms has tended to ignore that the patterns of knowledge sourcing might vary for different job positions. Usually, the studies are based on surveys or interviews with 'firm representatives', which tend to be senior managers, and the results are subsequently explicitly or implicitly extrapolated for all types of R&D work, which can include management practices around R&D as well as purely technical activities. However, managers often do not know all the details about the engineers'/developers' knowledge sourcing behaviour (Dahl and Pedersen, 2004). Given that the nature of work of senior managers[2] can be quite different to purely technical R&D

[2] In this study, the term 'senior managers' refers to managing directors or directors of R&D/chief technology officers who manage a technical team. 'Purely technical' R&D workers refers to all other R&D workers who do

workers, there might be significant variation in terms of knowledge sourcing. More specifically, it seems that the institutionalised role of senior managers tends to involve different patterns of social interaction compared to the environment of technical workers. A widely discussed online essay by the prominent programmer, venture capitalist and essayist Paul Graham (2009), highlights this important difference: whereas the manager's schedule is centred around meetings and often involves more speculative, exploratory social interactions, the so-called makers (people such as programmers or writers who make things) often need to avoid social meetings to be able to concentrate on their work. Consequently, one could maintain that the role of senior managers tends to automatically involve frequent social interaction with external people such as collaborators or clients. In contrast, it seems plausible to argue that the role of R&D workers in purely technical positions tends to be more focused on R&D work within the company with less institutionalised personal interaction with external actors. In particular, one could suspect that junior workers in the lowest job positions tend to be least involved in interaction with external relationships outside of one's organisation and their learning behaviour is most centred on internal resources.[3] Furthermore, people in lower job positions tend to have less work experience in different organisations. Since mobility between organisations is an important generator of inter-organisational personal networks (Dahl and Pedersen, 2004; Huber, 2012b; Mason et al., 2004), this seems to make it even more likely that they do not know external people which could be helpful for knowledge sourcing. On the basis of these arguments, one can formulate the following hypothesis, which has not been empirically tested before:

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not have any senior managerial function. Table 1 in section 3 outlines the hierarchical classification of job positions used in this article.

[3] One could argue that junior engineers or developers are less likely to be involved in institutionalised social events with external people because of their lack of experience in representing their organisation professionally. Also, because of the need for junior workers to learn about the internal operations, it seems likely that their knowledge sourcing behaviour and socialisation tends to be more centred on internal colleagues (Morrison, 2002). Exceptions to this trend might exist such as junior engineers who mainly deal with clients requests.

Hypothesis 1. *The lower the job position of R&D workers, the less important are external personal knowledge networks for their work.*

2.2.2. Differentiating between knowledge functions: problem solving versus exploration

Furthermore, to gain a better understanding of the importance of external personal knowledge relationships, it is useful to differentiate between knowledge functions. Personal relationships might be useful for certain R&D activities but less useful for others. Whilst several distinctions in terms of R&D activities could be made, arguably, one of the most fundamental distinctions is between focused problem solving and general exploration of new technological developments. This is related to the debate on exploration versus exploitation (March, 1991). The latter has focused on separating exploitation as the efficient use or refinement of current assets and capabilities from exploration as experimentation with new alternatives and the development of new capabilities (Gilsing and Nooteboom, 2006; March, 1991). Whilst this debate is based on the organisational level, a contribution of this article is to examine the respective issues from an individual R&D worker's point of view. For individual R&D workers, work involves two challenges: first, one needs to solve specific problems, and second, one needs to keep up-to-date with new technological developments on a general level. The latter can subsequently act as a resource for problem solving; yet keeping up-to-date is exploratory and not necessarily related to solving practical problems.

Importantly, the role of external personal knowledge networks might vary for those knowledge functions. On the one hand, since keeping up-to-date with new developments involves exploring new ideas, which often have not found their way into formal knowledge channels such as magazines, journals or patents, informal relationships might be critical (e.g.

Gilsing and Nooteboom, 2006). Personal contacts outside of one's organisation can enable access to a diverse pool of knowledge and therefore seem particularly useful for exploration. On the other hand, for solving a specific work-related problem, respective internal organisational resources might tend to be more relevant[4] and diverse external personal contacts might be less helpful, because they are often unrelated to the specific problem. Hence, this article aims to examine the following previously unexplored hypothesis:

Hypothesis 2. *For R&D workers, external personal knowledge networks are more important for keeping up-to-date with the latest technological developments than for problem-solving.*

2.2.3. Differentiating between sources of competitiveness

Furthermore, the role of external personal knowledge networks might vary according to the sources of competitiveness of the firms. Innovative firms can be driven mainly by being cutting-edge in technology. This can be based on cutting-edge scientific expertise or on superior engineering knowledge. However, alternatively, the competitiveness can derive from superior knowledge about market needs, in particular from feedback from customers or suppliers (e.g. Ulnwick, 2005; Von Hippel, 1988).[5] This paper will examine the potential effect of these sources of competitiveness by contrasting firms that are primarily driven by cutting-edge technology, with firms that are primarily driven by cutting-edge market knowledge (cf. Table 2 below).

In terms of theoretical expectations, there is uncertainty regarding the importance of external personal knowledge networks for different sources of competitiveness. On the one

[4] Arguably, there might also be interdepartmental barriers to knowledge transfer, particularly in larger organisations.

[5] Within this context, Asheim and Gertler (2005) have developed a distinction of knowledge bases for innovation. Their distinction between an analytic knowledge base versus synthetic knowledge base is centred on new scientific knowledge versus recombinant engineering knowledge. Yet, this paper distinguishes between competitiveness driven by technological knowledge (which can be analytic or synthetic), market knowledge and other types.

hand, one could argue that for primarily technology-driven firms, external personal networks are more important: in cutting-edge technological fields, access to strategic business knowledge and technological knowledge through personal contacts can be critical, because knowledge can be uncodified and there is often a time-lag between the development of knowledge and codification and subsequent publication in the public domain (Cowan et al., 2000). However, on the other hand, one could argue that for primarily technology-driven firms, much of the knowledge is available through codified public information such as publications or patents or through other sources such as online communities such as online discussion forums for software engineers. Particularly in the IT sector, this can make external personal networks less important. In contrast, for firms that are driven by market knowledge, external personal contacts with clients or suppliers might be much more critical than for technology-driven firms. In the light of these uncertainties, this study aims to test these two competing hypotheses, which have not been explored before.

Hypothesis 3-a. *R&D workers in primarily technology-driven firms find external personal knowledge networks more important for their work than R&D workers in primarily market-driven firms.*

Hypothesis 3-b. *R&D workers in primarily technology-driven firms find external personal knowledge networks less important for their work than R&D workers in primarily market-driven firms.*

2.2.4. Unique types of knowledge through personal networks

Another important but unexplored issue is which type of knowledge can be accessed only through external personal networks. To contextualise the role of external personal networks,

the question whether they represent a unique channel for knowledge, which cannot be acquired through any other means, is important. According to the resource-based view in strategic management (Barney, 2007), ownership or access to rare valuable resources is positively related to competitive advantage, which positively affects firm performance. This suggests that external personal networks can be particularly beneficial if they enable access to rare types of valuable knowledge, which cannot be accessed through any other means. To explore these issues, this paper examines which types of knowledge can be uniquely accessed through external personal networks. Importantly, as the discussion in section 2.2.1 suggests, job positions might matter. In particular, if personal networks are more important for senior managerial people, it might be that the unique type of knowledge tends to concern business knowledge rather than technological knowledge. For the purpose of this article, the term *business knowledge* refers to all non-technological forms of knowledge including organizational knowledge, managerial and entrepreneurial knowledge, knowledge about the customers and the market, and knowledge about suppliers and competitors. One could argue that much of the technological knowledge relevant for more junior, non-managerial technical R&D workers in IT tends to be available either via internal communication channels or via codified forms such as publications or the Internet. Yet, whether this argument holds true remains to be explored empirically, since uniquely acquired knowledge could also concern technological knowledge.

Hypothesis 4. *Knowledge that can uniquely be acquired through external personal networks—that is, knowledge that cannot be acquired through any other means—tends to concern business knowledge rather than technological knowledge.*

3. Material and methodology

Since much of the literature on inter-organisational networks has focused on regional economies, the study focuses on Cambridge being one of the prominent high-technology regions. The IT sector is used as an empirical focus because it constitutes the dominant sector of the 'Cambridge phenomenon' in terms of the number of innovation-based businesses (LibraryHouse, 2004). Within IT, this study looks at the dominant product-based sub-sectors hardware and software (excluding purely service-based companies).

The list of the firms in the target population was constructed by merging two existing databases on innovation-based firms from the research and consultancy companies 'Library House Ltd.' and 'Cambridge Investment Research Ltd.'. The target population (sampling frame) at firm-level consists of 220 firms, 156 in software and 68 in hardware. The sample is constituted by first taking a random sample of 100 firms (70 in software, 30 in hardware; that is, the proportions of the sub-sectors in the sample mirror the target population). Within those, the firms were asked to select R&D workers[6] according to the following criteria (if applicable): the managing director if s/he is actively involved in research or development; the director of research or development or chief technology officer; one 'key' engineer/developer who is regarded as most important for the firm; one senior engineer/developer (e.g. project leader); one mid-level engineer/developer; one junior engineer/developer with less than two years of work experience in the industry.

Getting access to the firms was challenging. After 11 months, data from 105 individuals in 46 firms were collected. Taking a multi-method approach, face-to-face meetings with the

[6] Only the firms possessed complete lists of their R&D workers, and it was not possible to get access to the lists. As a consequence, it was not possible to compare the sample with the population in greater detail. Also, the selection of interviewees by firm representatives might have led to a selection bias. For instance, firms might have avoided selecting introverted R&D workers with poor social skills; however, this bias would rather strengthen the results on the limitations of external personal networks, because introverted R&D workers are likely to be less socially active.

R&D workers were arranged and structured questionnaires as well as semi-structured interviews were used (average duration 45 minutes). The interviewees were briefed about the meaning of the terms 'personal networks' for the purpose of this study. In particular it was emphasised that it is about personal relationships which can be purely private or professional as long as it involves personal acquaintance and the work-related knowledge interaction goes beyond official duties; moreover, those personal contacts do not need to be based within the Cluster but can be located anywhere in the world.

The recorded interview material was fully transcribed. Using ATLAS.ti software, the quotes were systematically coded, and those codes were categorised into meta-concepts (in particular, regarding the unique types of knowledge acquired). The standardised survey questions were the basis for statistical analyses including simple t-tests and ANOVA to examine differences between groups.[7]

Let us examine some key characteristics of the sample. Out of 100 firms in the sample, 46 participated, which represents a response rate of 46% of the firms. Among those, 25 firms (54%) are in software, and 21 firms (46%) in hardware, which means that hardware is over-represented in the data (recall that around 70% of the firms in the target population are in software and around 30% in hardware). At the individual level, 58 respondents (55%) are in software, and 47 (45%) in hardware, which again shows that that hardware is over-represented.

Cambridge IT companies tend to be small with only very few exceptions. The average firm size in terms of the number of employees (full-time head count) is 35 for the Cambridge sites (median 20) and 81 for all locations world-wide (median 30). On average there are 17 R&D workers in each firm site in Cambridge (median 9).

[7] Because of the small sample size and the specific nature of the research hypotheses, more advanced statistical modelling is neither necessary nor appropriate.

Table 1 outlines the job position of the respondents in the sample, which shows that people in senior (engineering/development or managerial) positions are over-represented.

Table 1. Job positions of the respondents (N = 105)

	N	%
R&D managers	**47**	**44.8%**
Managing directors	14	13.3%
Directors of R&D or chief technology officers	33	31.4%
'Pure' engineers/developers	**58**	**55.2%**
Senior engineers/developers	34	32.4%
Mid-level engineers/developers	17	16.2%
Junior engineers/developers	7	6.7%

The respondents are highly educated with 26.5% having Ph.D. degrees, 31.4% Master's degrees and 35.3% Bachelor's degrees as their highest degrees.

To characterise the nature of the IT firms in the Cambridge Cluster, Table 2 outlines which type of knowledge is regarded the main source of competitiveness by the respondents.[8]

Table 2. Type of knowledge which is rated most highly for contributing to the competitiveness of the firm.

	Technology	*Market-needs*	*Marketing*	*Management*	*All four rated equally*	*Technology AND market-needs*	*All other combinations*	*Total*
Software	***37.9***	***24.1***	***3.4***	***0.0***	***8.6***	***17.2***	***8.6***	***100.0%***
Hardware	***55.3***	***10.6***	***2.1***	***2.1***	***6.4***	***17.0***	***6.4***	***100.0%***
Total	***45.7***	***18.1***	***2.9***	***1.0***	***7.6***	***17.1***	***7.6***	***100.0%***

"Cutting-edge knowledge can be an important source of competitiveness for firms. With regard to the product you are working on: to what extent does your firm hold cutting-edge knowledge in the following areas that contributes to its competitiveness?" (% of respondents, N=105). 7-point Likert scale from "1=very much" to 7="not at all" and alternatively "Don't know". The types of knowledge are: "*Technological* knowledge", "Specific knowledge about *market needs* gained from *feedback from customers or suppliers"*, "General knowledge in *marketing"*, "Knowledge in *management* (e.g. how to organize projects effectively and efficiently)".

[8] Note that the units of analysis—here and throughout the paper—are individual R&D workers; their assessment of firm characteristics is based on their individual experiences.

The knowledge base of the software industry has been characterised as being centred on incremental change using widely available technologies rather than radically new scientific knowledge (Steinmueller, 2004). Although several software firms in the sample operate exactly in this mode, the Cambridge software industry seems to be special in containing many firms that apply cutting-edge technology (e.g. new mathematical algorithms) to develop products (37.9%).[9] In this article, the term technology includes not only functional physical artefacts but also 'immaterial' formal methods or procedures. For hardware companies, as one might expect of this sector, cutting-edge technology is more important than in software: more than half of the R&D workers (55.3%) are in technology-driven companies and only 10.6% in market-driven ones.

4. Results and discussion

Each of the following sub-sections (4.1. to 4.4.) will address a hypothesis as developed in section 2 (hypothesis 1 to hypothesis 4).

4.1. External personal networks vis-à-vis alternative sources of knowledge for different job positions

This section evaluates the relative importance of external personal knowledge networks in contrast to other sources for problem solving and keeping up-to-date. The specific focus is on examining whether there are differences regarding job positions, which enables us to test hypothesis 1. The interviewees were asked to describe their knowledge sourcing practices for problem-solving and keeping up-to-date with new technological developments. In particular,

[9] Also, recall that the sample does not include purely service-based companies.

the role of colleagues within the firm in the respective site[10], other colleagues within the firm but in other sites, the internet (including online discussion forums), documents within the firm, professional publications, personal contacts from other firms or research institutions, chatting with strangers at events, and institutionalised customer/supplier relationships were discussed. Importantly, this can concern any type of knowledge, which is relevant for their job, not necessarily technological knowledge.

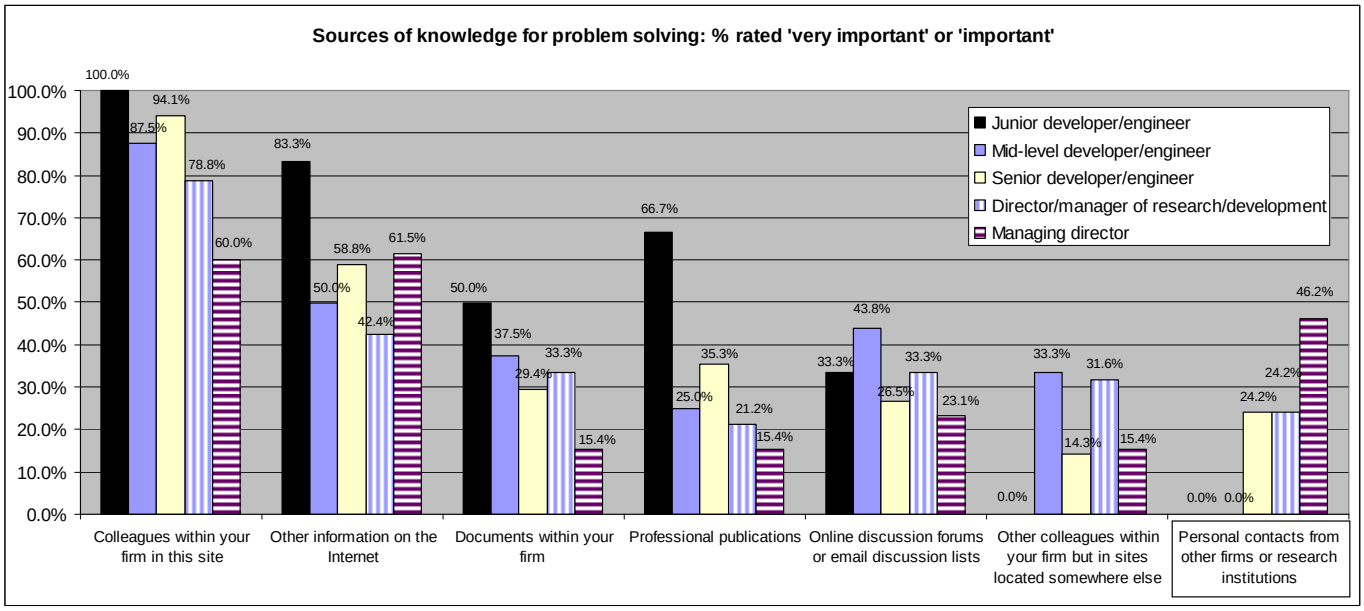
4.1.1. Problem-solving

The respondents rated the importance of various sources of knowledge for problem-solving on a scale from "1" (very important) to "7" (not important at all). Figure 1 shows the results for "1=very important" and "2=important". This highlights that colleagues within the firm in the respective site are the most highly ranked source of knowledge, particularly for non-managerial developers/engineers. Also the internet tends to be an important source across job positions. Interestingly, overall across all job positions, personal contacts outside of the company are the least important source.

Importantly, the results show that job position matters. A one-way between subjects ANOVA confirms that there is a statistically significant effect of job position on the importance of external personal networks for problem solving ($p=.001$). Specifically, whereas 46.2% of the managing directors rated personal networks as (very) important, this is only the case for 24.2% of the R&D directors/chief technology officers as well as the senior developers engineers/developers. And interestingly, no junior and no mid-level engineer/developer rated external personal networks as important.

[10] The question whether colleagues on the same site were working in other departments was not examined.

Figure 1. Sources of knowledge for problem solving.



"When you faced a problem in your work and you did not know a solution, how important were the following sources of knowledge (e.g. information, know-how) for you in the past year?" (1 = Very important, 7 = Not important at all, N = 104).

In contrast to people in senior managerial job positions, engineers/developers rely heavily on internal colleagues, documents and professional publications. Generally, for engineers/developers a frequently mentioned approach for sourcing knowledge is a combination of colleagues and the internet:

> *"Usually the first step is just google to see what there is. And if the problem is anything related to our work, there will be someone in this building who will be an expert on it, so the first step is somebody here. […] Much of the stuff I do is experience based and people here know. And other people move to this company and that's how knowledge gets passed" (principal engineer, medium-sized hardware company).*

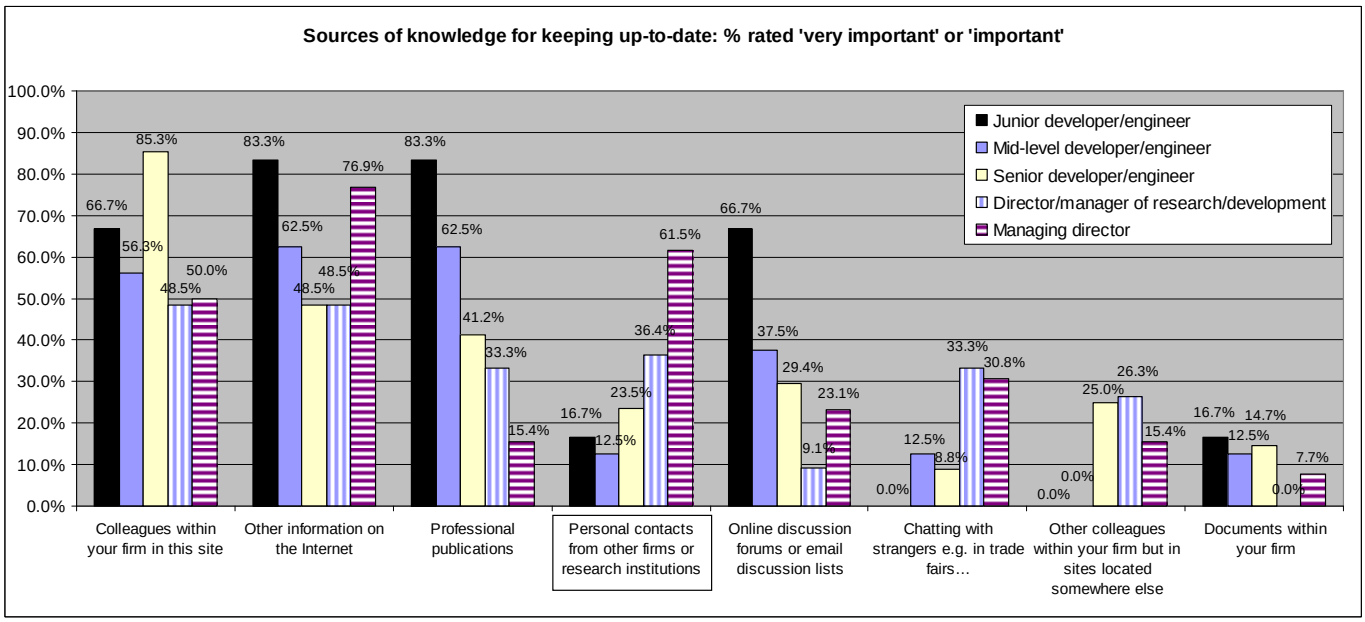
This quote also underscores the importance of experience-based learning and labour mobility; people from other firms bring in their experience-based, embodied knowledge and can subsequently act as a local source of expertise within the company. Together with other sources, including online discussion forums/email discussion lists, those engineers/developers tend to have sufficient access to relevant internal and external knowledge so that they do not find external personal knowledge relationships important for their problem-solving activities.

The results are in line with the arguments by Whelan et al. (2010) that the internet has become important for modern gatekeeping activities linking external and internal communication.

4.1.2. Keeping up-to-date with new technological developments

Furthermore, next to problem-solving, keeping up-to-date with new technological developments is another important knowledge activity.

Figure 2. Sources of knowledge for keeping up-to-date with new technological developments.



"Keeping up-to-date with the latest work-related technological developments (new potential solutions, tools, techniques) can be crucial and can be a challenge. How important are the following sources of knowledge (e.g. information, know-how) for you to be informed about and assess the importance of the latest technological developments?" 1 = Very important 7 = Not important at all (N = 104)".

Figure 2 shows that, relative to other sources of knowledge, personal contacts from other firms or research institutions are slightly more important compared to problem-solving (see section 4.2 for a detailed discussion). However, also here colleagues within the site, and the internet are by far the most important sources. Several of the engineers/developers explicitly emphasised that external personal contacts are not necessary for keeping up-to-date (as well as problem-solving) and are no prerequisite for being successful in their job.

Figure 2 again illustrates that in terms of (very) important sources of knowledge, personal networks are significantly more important for senior managers: whereas only 16.7% of the junior, 12.5% of the mid-level and 23.5% of the senior engineers/developers find external personal contacts (very) important, 36.4% of the R&D directors/chief technology officers and 61.5% of the managing directors find them (very) important.

The following quote illustrates that much of this difference might have to do with the institutionalised job roles of senior managers, who are naturally more involved in meetings and social interactions with internal and external people.

"The further up I got in the company, the more meetings I got involved in, and in the end I thought 'this is ridiculous'. I spent half of my day literally sitting around listening to other people talking. We are not doing anything, we are not producing anything. That was in the early 80s, I had money to burn and started my own company (Director of Engineering, micro-sized hardware company)."

That is, this engineer felt uncomfortable moving up the rank to a senior managerial position in his previous company because he prefers to do 'real' engineering/development work rather than sitting in meetings. Several other interviewees indicated similar critical or cynical views on senior managers, who talk all the time but do not do any 'real work'. All this suggests that because of institutionalised job roles, senior managers tend to be more exposed to internal and external people, which seems to be an important reason, why external personal networks are much more important for them than for more junior engineers/developers. A one-way between subjects ANOVA confirms that there is a statistically significant effect of job position on the importance of external personal networks for keeping up-to-date ($p=.031$).

4.1.3. Discussion

Overall, the results strongly suggest that the role of external personal networks in R&D problem solving varies significantly according to the job positions. In broad terms, the results

support hypothesis 1: the lower the job position, the less important are external personal knowledge networks.[11] In particular for managing directors, external personal networks tend to be important for problem solving and keeping up-to-date with new developments. Yet, for people in purely technical, non-managerial job positions, this does not tend to be the case, and alternative sources of knowledge tend to be significantly more important than external personal networks. This is most pronounced for junior and mid-level engineers/developers: for none of them external personal networks seem to be important for problem solving, and for only very few they are important for keeping up-to-date. Whilst these results are in contrast to those literatures that have emphasised the general importance of external personal knowledge networks, this does not mean that there are no inter-organisational knowledge linkages at all: many engineers/developers indirectly communicate via professional publications, other information on the internet or interactive online discussion forums/email discussion lists, which leads to 'virtual knowing' (Amin and Roberts, 2008) in online communities (Dahlander et al., 2008). That is, whilst the role of external personal knowledge networks is limited for engineers/developers, they are heavily involved in alternative relational configurations of inter-organisational knowledge linkages.

Overall, the results support the view that job positions define institutionalised roles about the nature of the work, including roles about social interaction, which subsequently shape the knowledge sourcing behaviour and the importance of external personal networks.

[11] In a strict sense, when considering each job category, the statistical relationship is not perfect. For problem solving, junior and mid-level engineers/developers, as well as for senior engineers/developers and R&D directors/chief technology officers, the importance of external personal networks is the same. Furthermore, for keeping up-to-date, junior engineers/developers rated external personal networks slightly more important than mid-level engineers/developers. However, overall, and considering statistical fluctuation, the general trend still holds that higher job positions make it more likely to find external personal networks important.

4.2. External personal networks: problem solving versus keeping up-to-date

In order to address hypothesis 2, let us now reflect on the potential difference in the role of external personal networks for problem solving versus keeping up-to-date with new developments. Figure 3 depicts the mean ratings (1 = very important, 7 = not important at all) for each job category.

Table 3. The importance of external personal networks for problem solving versus keeping up-to-date.

	Job position	Mean rating (1=very important, 7=not important at all)	Std. dev.
Problem solving	Junior developer/engineer	5.5	1.8
	Mid-level developer/engineer	5.6	1.4
	Senior developer/engineer	4.2	2.0
	Director/manager of research/development	4.2	2.0
	Managing director	2.8	1.7
Keeping up-to-date	Junior developer/engineer	4.3	2.0
	Mid-level developer/engineer	4.6	1.7
	Senior developer/engineer	4.2	1.8
	Director/manager of research/development	3.8	2.0
	Managing director	2.5	1.2

Mean ratings on a Likert scale from 1 = Very important 7 = Not important at all (N = 104)

This shows that for each job category, external networks are more important for keeping up-to-date than for problem solving. The differences are most pronounced for junior (5.5 for problem solving versus 4.3 for keeping up-to-date) and mid-level developers/engineers (5.6 for problem solving versus 4.6 for keeping up-to-date).

Across all job positions, there is a statistically significant difference between the mean ratings of personal contacts for problem solving (4.39) and keeping up-to-date (3.95) (paired samples t-test, p=0.013). This confirms hypothesis 2 that external personal knowledge networks are more important for keeping up-to-date with the latest technological

developments than for problem-solving. These results suggest that next to job position, knowledge functions need to be considered for comprehending the role of external personal networks for R&D workers. For specific problem solving practices they tend to be significantly less important than for more unstructured, general exploration activities.

4.3. Contrasting sources of competitiveness

To test hypothesis 3a/b, let us now examine whether the importance of external networks vary according to the sources of competitiveness of the firms the R&D workers are working for. As discussed in section 2.2.3, in particular whether a firm's competitiveness is based on cutting-edge technology can matter. In the following, the analysis distinguishes between (i) the cases where the R&D workers regarded being cutting-edge in terms of technological knowledge as the most highly ranked source of competitiveness of their firm, (ii) the cases where knowledge about market needs is most highly rated, and (iii) all other cases. Recall Table 2, which outlined that about 46% of the respondents regarded being cutting-edge in terms of technological knowledge as the most important source of competitiveness.[12] The other cases are mainly based on cutting-edge knowledge about market needs (18%) or a combination of cutting-edge knowledge about technology as well as market needs (17%). Table 4 shows the mean ratings of the importance of external personal networks (problem solving and keeping up-to-date) for the respective sources of competitiveness.

[12] The sources of firm competitiveness were assessed by each individual R&D worker with regard to the product they are working on.

Table 4. Contrasting the importance of external personal knowledge networks for different sources of competitiveness

	Sources of competitiveness	**N**	**Mean rating** (1=very important, 7=not important at all)	**Std. dev.**
Importance of external personal contacts – *problem solving*	Technology-driven	45	3.9	1.9
	Market-driven	19	5.0	2.0
	Other	40	4.7	2.0
Importance of external personal contacts – *keeping up-to-date*	Technology-driven	45	3.2	1.5
	Market-driven	19	5.1	1.8
	Other	40	4.3	2.0

(N = 104)

The results show that for primarily technology driven competitiveness, external personal networks are significantly more important than for other types of competitiveness. This is the case for problem solving (rating 3.9 versus 5.0/4.7) and even more so for keeping up-to-date (rating 3.2 versus 5.1/4.3). A one-way within subject ANOVA shows a significant effect (p=0.06 for keeping up-to-date and p=0.00 for problem solving) of the source of competitiveness on the importance of external personal networks. Turkey post-hoc comparisons indicate that for technology-driven companies, external personal networks are significantly more important regarding keeping up-to-date than for market-driven ones (p=0.00) and for other companies (p=0.01). Also regarding problem solving—considering the small number of respondents—the differences are considerable (p=0.11 compared to market-driven and p=0.13 compared to other companies).

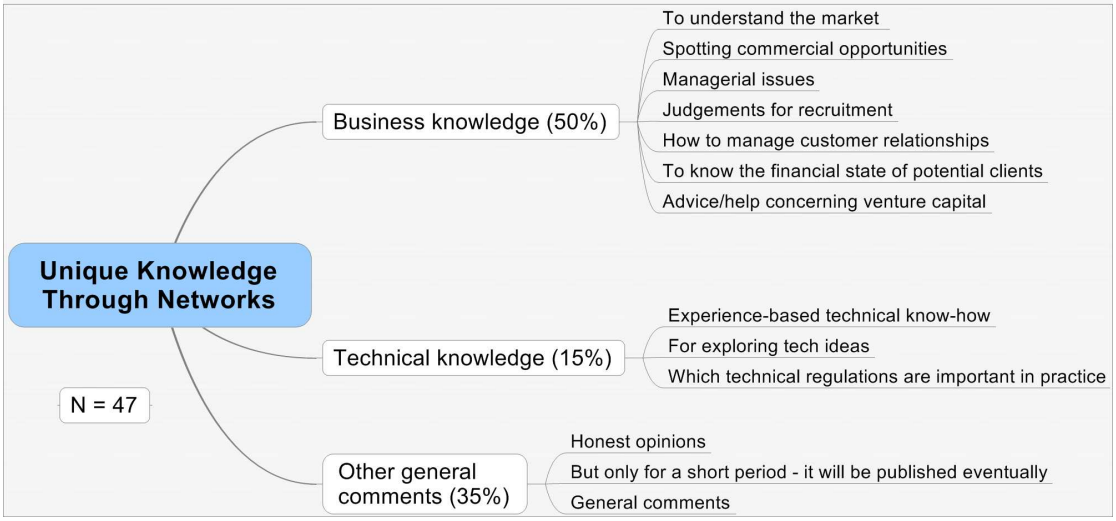
Hence, hypothesis 3a can be confirmed and hypothesis 3b can be rejected. R&D workers in primarily technology-driven firms find external personal knowledge networks more important for their work than R&D workers in firms primarily driven by market knowledge. This shows that firm variation in terms of the sources of competitiveness needs to be considered for understanding knowledge sourcing in R&D.

4.4. Unique sources of knowledge through personal networks

Having provided an overview of the importance of personal networks vis-à-vis alternative sources, let us now be even more specific about their exact role and test hypothesis 4. The interviewees were asked whether there are any types of work-related knowledge—again, not necessarily technological knowledge but any kind which is relevant for their job—that can *only* be accessed through personal networks (and not through any other medium). As discussed in section 2.2.4, according to the resource-based view, such valuable and rare knowledge channels can be particularly important for contributing to organisational competitiveness. The qualitative responses were categorised into types of knowledge.

Interestingly, more than half of the respondents emphasised that they do not think that there is any knowledge of this type. In several cases, the respondents put forward reasons why personal networks can be helpful, but they highlighted that they could also access this type of knowledge through other sources. Figure 3 shows the types of work-related knowledge which the R&D workers could only access through personal networks.

Figure 3. Unique knowledge acquired through personal networks



Importantly, the most frequent class of knowledge—mentioned by nearly 50% of the respondents and primarily senior managers—is *business knowledge*. A typical response is the following, which demarcates business knowledge from technological knowledge:

> *"I think business information is what we talk about, because the technical information is, I think, becoming increasingly available on the internet" (head of development, micro-sized software company).*

The most frequent response is that networks are helpful for senior managers in terms of *understanding the market*, which is illustrated by the following quote:[13]

> *"For instance, gossip. […] Through chit-chat you can find out about other companies, what people are doing, where they are moving from and to, you really can't get that kind of information very easily any other way. So, this helps you build a picture of the market as it really is. […] So you can find out in a few minutes chatting what products perhaps people are interested in developing, whether they are moving into another market, whether they are addressing this successfully" (managing director, small software company).*

That is, external personal networks enable access to knowledge about strategically important developments of other firms in the market. This is a theme that has been emphasised by various authors in the literature on regional learning and innovation (Bathelt et al., 2004; Malmberg and Maskell, 2002); yet, importantly, it only concerns business knowledge. Related to this, two respondents mentioned the spotting of commercial opportunities as a unique kind of knowledge.

Furthermore, many respondents in senior-managerial positions find networks useful for *managerial issues*: they provide unique possibilities to find out and discuss about how to manage people. Also in terms of recruitment personal networks can be essential for judging other people. Moreover, one respondent learned *how to manage customer relationships*, and

[13] Whilst the quotations in this section might appear anecdotal, the reason for discussing them is to substantiate the nature of the kinds of knowledge.

one managing director emphasised that *getting to know the financial state of potential clients* is useful. Finally, one respondent emphasised that personal networks were essential for *advice/help concerning venture capital*.

The second broad category of knowledge uniquely acquired through personal networks is *technological knowledge*, which, interestingly, has mainly been stated by respondents working in hardware. However, in contrast to business/commercial knowledge, this type is only mentioned by few respondents (about 15%).

The most frequently stated reported sub-type is *experience-based technical know-how*, mentioned only by hardware engineers as the following quote illustrates:

> *"In electronics there is a lot of rules of thumb and there is stuff, you know, you do a college course or a university course and you might be qualified, but it's not the same as the knowledge that people get from actually doing it for real" (senior engineer, small hardware company).* [14]

However, one has to bear in mind that much of the learning of experience-based knowledge happens through learning from colleagues within the firm rather than external personal networks.

Furthermore, a few interviewees mentioned exploring technical ideas, in particular on cutting-edge technologies, as unique types of knowledge only available through personal networks, which supports the results on the significance for exploration in section 4.2.

Moreover, one person remarked that assessing which codified technical regulations are actually important in practice is a non-trivial issue which can only be resolved through personal networks.

[14] Interestingly, all of these cases concern physical materials. This suggests that accessing uncodified technical know-how largely concerns material objects rather than 'immaterial' intellectual problems.

Third, about 35% of the respondents made *other general comments* on the usefulness of personal networks. First, several people emphasised that personal relations with people you trust (regarding competence) can be critical for getting *honest opinions* (both in terms of technical and business knowledge). That is, personal networks help to differentiate between 'strategic' marketing and independent opinions. This can involve technological knowledge as well as business knowledge.

Furthermore, several R&D workers—yet from only very few companies—emphasised that personal networks are useful as unique sources of knowledge but *only for a short period*, because *it will be published eventually*. However, many people from companies that are also technologically cutting-edge, did not state that this is the case for them.

Overall, these results confirm hypothesis 4 that knowledge which can uniquely be acquired through external personal networks tends to concern business knowledge rather than technological knowledge. This reinforces the results in section 4.1 that job positions matter and that external personal networks are most important for people in higher positions: business knowledge that can uniquely be acquired through external personal networks is mainly useful for people in senior managerial positions. Furthermore, the result that more than half of the respondents could not identify any unique kinds of knowledge reinforces the previous findings of section 4.1 that—in the light of alternative sources of knowledge—the role of personal knowledge networks should not be overrated.

5. Conclusions

5.1. Contribution to the academic literature

This paper has sought to critically investigate the widespread view that external personal knowledge networks are important for R&D workers in innovative firms. It contributes to a more nuanced understanding of whether, and in which contexts, external personal knowledge networks are important for innovation-based IT firms in a high-tech cluster. The study complements previous studies on firm-level knowledge networks by systematically investigating the knowledge sourcing behaviour of individual R&D workers in different job positions. Importantly, this offers a better understanding of the importance of external personal networks by contrasting their significance with alternative sources of knowledge. Furthermore, the paper leads to novel contingency theoretic insights into previously unexplored factors that clarify contexts in which external personal networks are significant or unimportant.

More specifically, the first contribution of this paper is to show that the knowledge sourcing behaviour varies according to *job positions*. The results suggest that the lower the job position, the less important are external personal knowledge networks. Whilst for managing directors, external personal networks tend to be important, this does not tend to be the case for purely technical, non-managerial R&D workers. The latter group finds alternative sources of knowledge such as internal colleagues or the internet significantly more significant. For non-managerial workers, inter-organisational knowledge relationships tend to operate via professional publications or online discussion forums rather than via personal networks. This suggests that, instead of assuming that external personal knowledge networks are of general importance, theories on inter-organisational knowledge networks need to

account for job positions. The institutionalised job roles seem to affect knowledge sourcing behaviour and requirements.

These results were reinforced by the second contribution of this paper: the significance of external personal networks vis-à-vis alternative sources of knowledge was scrutinised by examining the *kinds of knowledge that are available uniquely through external personal networks*. The results reveal that the most frequent type concerns business knowledge rather than technological knowledge. This strengthens the findings that personal networks are most important for managerial job positions. In the light of the resource-based view, such access to valuable and rare business knowledge is particularly relevant for competitiveness.

Furthermore, the third contribution of this paper is to show that the usefulness of external personal networks varies for *knowledge functions*: they are significantly more important for exploratory practices of keeping up-to-date with the latest technological developments than for more focused problem-solving practices. This examination of the individual-level equivalent of the firm-level concepts of exploration versus exploration contributes to a better understanding of the type of knowledge activities for which external personal networks are most beneficial.

Finally, the fourth contribution of this article is to illustrate that firm variation regarding the *sources of competitiveness* need to be considered for comprehending the relevance of external personal knowledge networks. The latter are more important for primarily technology-driven firms that gain competitiveness through cutting-edge technological knowledge than for firms driven by other factors such as knowledge about market needs.

Overall, the results suggest that academic theorising on inter-organisational knowledge networks such as Open Innovation should not assume that personal networks are generally important for R&D workers in innovative firms. The paper complements previous findings, which have already pointed out some limitations of external personal networks (e.g. Edelman

et al., 2004; Ibrahim et al., 2009; Isaksen, 2004; Lechner and Dowling, 2003; Waters and Lawton Smith, 2008; Zhang, 2010). It contributes to a more nuanced contingency theoretic understanding of external personal knowledge networks for R&D workers by highlighting critical variation in terms of job positions, knowledge functions and sources of competitiveness.

5.2. Implications for policy and management

Many cluster and innovation policies as well as R&D management initiatives explicitly or implicitly assume that external personal networks are critical for R&D and innovation. The results of this paper suggest that generally facilitating external 'networking' can be misguided and needs to be re-thought. Rather than universally encouraging external personal networks, policies and initiatives should be targeted on contexts where external personal knowledge networks seem most promising. This complements previous findings in the small business and entrepreneurship literature, in particular the study by Lechner and Dowling (2003), which emphasised firm development phases. Specifically, the results suggest that networking initiatives should consider the significance of job positions. Since, in particular for non-managerial engineers, personal knowledge relationships outside of their organisation often seem of very limited significance, it seems most fruitful to concentrate fostering external personal knowledge contacts on senior-managerial job functions. For senior managers there is most potential for taking advantage of sourcing unique business knowledge through external personal networks. That is, the results suggest that personal network based non-pecuniary inbound open innovation strategies (Dahlander and Gann, 2010) benefit from focusing on senior managers, and they might be of limited use, or even irrelevant, for certain non-

managerial technical workers. For the latter group, facilitating external interactions in online communities (discussion forums) might often be more promising.

Furthermore, the results suggest that networking initiatives seem most fruitful for general exploration rather than for specific problem-solving. Hence, it might be useful for organisations to target networking initiatives for those specific individuals that are expected to pursue exploration, in particular for senior managers who aim to explore business opportunities. However, networking initiatives should be careful with R&D workers who need to focus on specific problem solving: for them external networking can potentially be a negative distraction from 'getting things done'.

Overall, these results support critical views on cluster and innovation policies that foster external networks, since those do not seem to be a general requirement for all firms and R&D workers (e.g. Romijn and Albaladejo, 2002). Again, those cluster and innovation policies might benefit from focusing on specific job positions, knowledge functions and types of firms.

5.3. Limitations and further research

Finally, the limitations of the study and questions for further research should be mentioned. Because the results are based on SMEs in the IT sector within one innovative region, there is a need for further research to explore whether similar patterns hold in other sectors and regions. The networking behaviour of engineers/developers in IT might be distinct. For instance, as Grabher and Ibert (2006) have argued, creative professionals in advertising are more active 'networkers' than people in software. Furthermore, it remains unclear whether service-based firms show different patterns than technology-based firms. There might also be national differences in networking behaviour as suggested by Dodd and

Patra (2002). There is a need for both, in-depth qualitative research as well as large-scale quantitative modelling to arrive at a better understanding of these dimensions.

Moreover, the study did not include all R&D workers in the respective firms. This produces uncertainty regarding the representativeness of the findings. In particular, the question whether some individuals do not need external links because they rely on gatekeepers could not be examined in detail.

Furthermore, because of the lack of empirical indicators, this study is based on perceptions and could not link the results to the innovative or economic success of individual R&D workers as well as the respective firms. Future research needs to clarify the effect of external personal knowledge networks on the individual performance of R&D workers as well as on firm performance. Within this context, the potential costs for inbound open innovation need to be examined (Dahlander and Gann, 2010). Moreover, to avoid a one-sided functional view of personal knowledge networks, the underexplored potentially negative effects of 'leakage' of knowledge through networks to competitors needs to be addressed by future studies.

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