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Abstract

The knowledge base concept in the past has often been applied in its „pure" form, i.e. it was assumed that there are dominant knowledge bases in particular sectors and firms, that shape the knowledge- and innovation process and related networks. For example, it has been argued that in the case of „analytical sectors" such as biotech codified knowledge generated by universities and R&D organisations are key for radical innovation, and that such knowledge is often transmitted by formal R&D cooperations and university-firm links. „Synthetic sectors" such as machinery on the other hand were assumed to innovate more incrementally by recombining existing knowledge that was often drawn from suppliers or service firms. Empirical literature partly has confirmed these basic patters, but also has demonstrated that more complex knowledge processes are underlying these overly schematic expectations. In addition, there have been arguments by Asheim, Boschma and Strambach, among others, more recently that combinations of different but related knowledge bases and -assets might be of high relevance for understanding innovation processes of firms in particular sectors and regions. This implies that innovation of firms e.g. in „analytical sectors"might benefit not just from new and basic knowledge generated by research, but also from recombining existing and applied knowledge or by drawing on symbolic knowledge assets. The same argument for the relevance of combinatorial knowledge bases applies for „synthetic" and „symbolic sectors", but in different forms. The paper investigages if the reliance on combinatorial knowledge bases leads to a better innovation performance and more radical forms of innovation than the use of more narrow knowledge assets. The paper investigates the relevance of combinatorial knowledge bases for innovation at first conceptually and based on respective literature. In the second part we analyse this question empirically by drawing on findings for the ICT sector in three regions of Austria (Vienna, Upper Austria, and Salzburg).

1 Introduction

Innovation is regarded as a key factor for firms in advanced countries in order to compete on global markets. What is more controversial is the question which factors and processes are relevant for firms to become and stay innovative. Innovation in this context is understood in a Schumpeterian sense, i.e. including the change of products, processes, organizations and markets. In the past two decades we have seen many approaches and studies dealing with key factors and processes for innovation such as firm capabilities (Nonaka and Toyama 2005; Zahra and George 2002; Nonaka and Takeuchi 1995), knowledge spill-overs (Jaffe 1986; Audretsch and Feldman 1996; Anselin, Varga, and Acs 1997; Breschi 2011), innovative mileux (Crevoisier 2004; Camagni 1991), innovation systems (Asheim and Gertler 2005; Tödtling and Trippl 2005; Cooke, Boekholt, and Tödtling 2000; Cooke, Uranga, and Etxebarria 1997; Doloreux 2002) and networks (Saxenian 1994; Giuliani 2007; Powell and Grodal 2005; Boschma and Ter Wal 2007). In the past few years the role of knowledge bases (Asheim and Coenen 2005; Asheim and Gertler 2005) and of sourcing and integrating knowledge from external domains (Tödtling, Lehner, and Trippl 2006; Tödtling, Asheim, and Boschma 2013; Asheim, Moodysson, and Tödtling 2011; Bathelt 2011) has moved into the foreground. The geographical scope of such knowledge relations has shifted from a predominant regional focus in the past like in the milieu and industrial districts literature (Saxenian 1994; Malmberg and Maskell 2002; Camagni 1991) to a local-global perspective (Bathelt, Malmberg, and Maskell 2004; Archibugi and Lundvall 2001), and to a multilevel or multiscalar view more recently (Asheim, Moodysson, and Tödtling 2011; Tödtling, Asheim, and Boschma 2013).

A key concept widely used in the past few years has been the knoweldge base approach (Asheim and Gertler 2005; Asheim and Coenen 2005; Moodysson, Coenen, and Asheim 2008; Martin 2013). It has often been applied in its „pure“ form, i.e. it was assumed that there are dominant knowledge bases in particular sectors that shape knowledge- and innovation processes and related networks of firms. In the case of „analytical sectors“ such as biotech, for example, codified knowledge generated by universities and R&D organanisations is said to be key for bringing forward new development and products, and that such knowledge is often transmitted by formal R&D cooperations and university-firm links. „Synthetic sectors“ such as machinery or engineering, on the other hand, were assumed to innovate more incrementally by recombining existing knowledge that was often drawn from suppliers or service firms. „Symbolic sectors“ such as creative industries or new media were seen to rely to a high extent on locally based tacit knowledge and capabilities, and innovate more often in project based networks.

Empirical literature partly has confirmed these basic patters (see e.g. Aslesen and Freel 2012; Tödtling and Grillitsch 2012) and the Special Issues to the European CRA project: (Asheim, Moodysson, and Tödtling 2011; Tödtling, Asheim, and Boschma 2013). However, it also has been demonstrated that more complex knowledge processes are in fact underlying these overly schematic expectations (Jensen et al. 2007; Halkier et al. 2010; Cooke et al. 2010). In addition, there have been arguments more recently by Asheim et al. (2011) and Strambach and Klement (2012), among others that combinations of different but related knowledge bases and -assets might be of high relevance for understanding innovation processes of firms in particular sectors and regions. This implies that innovation of firms e.g. in „analytical sectors“might benefit not just from new and basic knowledge generated by research, but also from recombining existing and applied knowledge or by drawing on symbolic knowledge. The same argument for the relevance of combinatorial knowledge bases applies for „synthetic“ and „symbolic sectors“, but in different forms. The present paper therefore investigages if the reliance on combinatorial knowledge leads to a better innovation performance and more radical forms of innovation than the use of more narrow knowledge bases. The paper analyses this topic at first conceptually and based on respective literature. In the second part we investigate this question empirically by drawing on findings for the ICT sector in three regions of Austria (Vienna, Upper Austria, and Salzburg).

2 The relevance of combinatorial knowledge – the view from the literature

There are rather few studies dealing explicitely with the role of combinatorial knowledge bases for innovation. Among those are Asheim et al. (2011), Manniche (2012), and Strambach and Clement (2012) that will be dealt with below. This to some extent has to do with the recent nature of the knowledge base concept (Asheim and Gertler 2005; Asheim and Coenen 2005). However, there are related arguments and findings in the literature that were pointed out already earlier.

2.1 Knowledge combination and the firm

The idea that innovation is based on new combinations goes back to Schumpeter (1911). But he was refering to new combination of means of production by the innovative entrepreneur that can lead to new products, processes, organisations or markets. He was not refering explicitly to knowledge. The knowledge concept, including the distinction between tacit and codified knowledge, has been introduced in the late 1950s and 1960s by Polanyi (1958, 1966). It has been moved to the center of the firm by Nonaka and Takeuchi (1995) in their book on the knowledge creating company. In the core of their theory is the knowledge spiral, the idea that knowledge in firms is generated by a two-dimensional process, having (1) an epistemological dimension, i.e. a conversion from implicit (tacit) and explicit (codified) knowledge and back, and (2) an ontological dimension referring to the conversion of knowledge from individuals to groups and further to organization. Applying these two dimensions results in the four modes of the knowledge spiral, the SECI model: **S**ocialisation (from tacit to tacit e.g. by sharing experiences), **E**xternalisation (codification of tacit knowledge), **C**ombination (new combinations of codified knowledge), and **I**nternalisation (conversion from codified to tacit e.g. through creating new routines). The transformation of knowledge from tacit to codified and its combination, thus, are in the center of the knowledge and innovation process. It has the two dimensions of combining and converting explicit and codified knowledge, and of converting knowledge at the level of individuals to those of groups and organizations. This takes place in a material and cultural context (called "Ba") in which knowledge is shared, created and utilized.

Similarly, Breschi and Lissoni (2001) have critisized a too schematic division between tacit and codified knowledge and emphasised the need to combine them in knowledge processes, whereas Cohen and Levinthal (1990) and Zahra and George (2002) have focussed on the relationship between external and internal knowledge in the firm. The central argument is that the absorption of external knowledge requires also certain internal capabilities in the firm such as the capability to search relevant external knowledge and to transfer and integrate it into the business processes of the firm. From these firm-centred approaches we can, thus, conclude that the innovative performance of firms depends on the combination of external and internal knowledge as well as on the combination of explicit (codified) and implicit (tacit) knowledge.

2.2 Combining learning modes

The need to combine codified and tacit knowledge has also been stressed convincingly by Jensen et al. (2007) applying the concept of learning modes (Lundvall and Johnson 1994) in an innovation survey for Danish firms. They distinguish between an STI (science, technology and innovation) mode of learning and a DUI mode (doing, using and interacting). They show that the largest share of firms engaged in learning processes could be attributed to the DUI mode and the smallest to the STI mode. However, there was a considerable segment combining DUI learning with STI learning.

STI learning has similar characteristics as the analytical knowledge base developed by Asheim and Gertler (2005, see below), i.e. knowledge generation based on science, R&D and codified knowledge, and a strong role of and links to universities, wheras the DUI mode comes close to the synthetic knowledge base, i.e. problem oriented learning „by using and doing", application oriented, and strong interactions with suppliers and clients. Key findings from the Jensen et al. (2007) study are that the probability for successful product innovation increases for firms using the DUI mode of learning. However, the authors find that „ … the most significant and important result is that firms using mixed strategies that combine organizational forms promoting learning with R&D efforts and with cooperation with researchers and knowledge institutions are more innovative than the rest. …". They conclude that „ .... what really improves innovation performance is using mixed strategies that combine strong versions of the two modes ..." (p. 690). A more case based approach was followed by Isaksen and Karlsen (2010) in their study and comparison on the marine biotechnology industry in Tromsoe (STI mode) and the equipment suppliers in Agder (DUI mode). They have also demonstrated benefits of combining different knowledge assets for these two industries. Although the approaches and distinctions of tacid/codified knowlege and of DUI and STI learning modes are highly useful, they suffer from a too simple dichotomy that to some extent has been overcome by the more differentiated knowledge base approach.

2.3 Combining knowledge bases

The knowledge base concept goes back to Laestadius (1998) and has been further developed by Asheim and Gertler (2005), Asheim and Coenen (2005) , Cooke et al. (2007), Moodysson et al. (2008), and Martin and Moodysson (2013). The concept distinguishes between a synthetic, analytical and symbolic knowledge base (SAS) that differ in several dimensions such as the kind and mix of knowlege involved (tacit/codified; scientific, practical, cultural), the way, how knowledge is generated (exploration, research and development, application and proplem solving), institutional contexts and dominant knowledge sources (universities and research organisations, transfer agencies, clients and suppliers, service providers, etc.) and knowledge outcomes (patents, new products, processes and technologies, designs and cultural artefacts).

The synthetic knowledge base seems to be the most widely used one (Halkier et al. 2010; Martin 2013). It characterizes sectors and firms with capabilities in combining knowledge from different domains. Typically, innovations are stimulated by interactions with clients or suppliers, or service firms. Tacit knowledge, often exchanged through face-to-face contacts, plays a high role in such contexts. The innovation output of such firms tends to be rather incremental, i.e. radical innovations based on scientific breakthroughs are rare. Sectors dominated by synthetic knowledge are e.g. machinery, engineering or automotives. The analytical knowledge base refers to sectors and firms that typically apply more formal innovation processes and R&D, even using scientific approaches for generating knowledge and innovation. Accordingly, such firms recruit staff with academic or scientific qualifications, often hired from universities. Codified knowledge plays an important role in the innovation process e.g. in terms of R&D inputs and -outputs (e.g. patents). Firms based on analytical knowledge tend to generate more radical technological product and process innovations. Typically, such a knowledge base can often be found in high-tech manufacturing sectors such as biotech or nanotechnology. Finally, the symbolic knowledge base characterizes sectors where fashion, culture and related artifacts and “symbols” play an important role. Typical industries would be media, advertising, design or music, where the capability to identify social trends and to address these trends with “fashionable” products are of key importance.

Such patterns of knowledge bases and innovation processes were identified in European empirical studies, in particular the CRA project (Tödtling, Asheim, and Boschma 2013; Asheim, Moodysson, and Tödtling 2011) and EURODITE project (Halkier et al. 2010; Cooke et al. 2010). However, these studies also demonstrated more complex patterns of innovation bringing forward evidence for the *combinaton* of knowledge bases in many of those sectors (Halkier et al. 2010). Similar arguments and findings were presented by Crevoisier and Jeannerat (2009), Asheim et al. (2011), Grillitsch and Trippl (2013), Manniche (2012), Strambach and Klement (2012). In particular the report on the EURODITE project (Halkier et al. 2010, p. 52 ff) is of interest here. It has studied the knowledge bases and their combination for 7 industries in 25 regions in Europe. The study has demonstrated that all of the investigated sectors were characterised not just by one dominant knowledge base, but also by mixes and combinations thereoff. The ICT sector that will be investigated here was characterised as predominantly synthetic, but showing features also of analytical and symbolic knowledge bases. A high percentage of ICT firms had combined synthetic and analytical knowledge.

There are also arguments and findings in the literature that are not explicitly but imlicitly related to the combinatorial view of knowledge. This applies e.g. to the „related variety“ approach, which suggests that knowledge in different but related sectors of the region matters for the economic performance of industries and also for innovation processes (Frenken, Van Oort, and Verburg 2007; Frenken and Boschma 2007; Boschma and Iammarino 2009). These authors stress the benefits of knowledge that is different but not too distant in a cognitive sense from concepts used in particular industries and firms.

2.4 Multilevel perspective

Also the geographical dimension of knowledge relations and in particular their multilevel character matters for combinatiorial knowledge dynamics. To some extent geograpy is an integral part of the knowledge base approach since symbolic and synthetic knowledge due to their more tacit and cultural nature are said to be to be highly localized, whereas analytical knowledge is more mobile and globalized (Martin and Moodysson 2013; Manniche 2012). However, geography and territory have also a generic role on innovation processes. Of key importance are institutional configurations on regional, national and higher levels. Theoretically these were captured in the literature on territorial innovation models such as industrial districts, innovative milieux, and regional- and national innovation systems.

In older innovation studies of the 1980s and 1990s the role of the region has been strongly emphasised. This applies in particular for the literature on industrial districts (Asheim 1996; Pyke, Becattini, and Sengenberger 1990) and on innovative milieux (Camagni 1991; Maillat 1998; Crevoisier 2004). In a similar reasoning Saxenian (1994) has emphasised the important role of regional culture and networks for innovation in technology regions such as Silicon Valley and Boston. The central argument was that knowledge relations in the region are more based on social relations, a common understanding, culture and trust, and as a consequence favourable for innovation (see also Gertler 1995, 2004). However, in particular, Camagni (1995), Grabher (1993) and Hassink and Shin (2005) also have highlighted the danger of „lock in“ in such inward looking milieux and as a conseqence have emphasized the role of external networks for regions to open up and to stay innovative. In Camagnis's view local milieu and external networks have different functions: Whereas the milieu, due to the common language and trust, stimulates the exchange of tacit knowledge and local learning, the networks are selectively opening up access to external complementary knowledge and resources. They allow the region to avoid lock-in and to stay innovative in the long run. Regions and firms that are able to combine milieu and networks, thus, are performing better. In the early 2000s the view shifted to the co-existence and complementarity of „local buzz and global pipelines“(Bathelt, Malmberg, and Maskell 2004) and their importance for the innovative performance of clusters (Maskell, Bathelt, and Malmberg 2006). This to some extent is a further development of Camagni's argument, since it also demonstrates the benefit of combining local and global knowledge relations. It also suffers from too strong simplifications as was pointed out by Trippl et al. (2009) and by Grillitsch and Trippl (2013).

Of relevance for understanding the territorial dimension of knowledge and innovation processes are the concepts or regional (RIS) and national innovation systems (NIS) since they constitute complementary institutional contexts for innovation processes of firms (Cooke, Boekholt, and Tödtling 2000; Cooke, Uranga, and Etxebarria 1997; Tödtling and Trippl 2005; Asheim and Gertler 2005; Doloreux 2002; Freeman 1995; Isaksen 2001; Lundvall 1992). Whereas the RIS contributes e.g. required qualifications and higher education, and supports networking, the national innovation system is often important for innovation finance, specialised research organisations and technology policy (Lundvall 2007). Furthermore, in the past two decaces also the European Union has taken on a more active role in supporting the European Research Area (ERA) and in setting up e.g. the Framework Program for research collaboration stimulating research networks at a European scale. Accordingy, recent studies on knowledge relations in the innovation process have pointed to the multi-level or multi-scalar nature and a highly differentiated character of institutional configurations and knowledge links (Gertler 2010; Strambach 2010; Hassink 2010; Grillitsch 2014). Empirical results suggest that the spatial configuration of knowledge links depend on the knowledge base of industries, size of firms, and type of RIS among others (Chaminade 2011; Asheim, Moodysson, and Tödtling 2011; Tödtling, Asheim, and Boschma 2013; Tödtling et al. 2013).

2.5 Previous empirical studies

There are some own previous empirical studies, highlighting the relationship between the innovation performance of firms (types of innovation) and the types and geography of knowlege sources. Tödtling et al. (2009) have shown for several industries in Austria that different types of innovation are relying on specific kinds of knowledge sources on particular spatial levels. This study has e.g. demonstrated, that incremental innovations were significantly related to knowledge relations with suppliers and clients at international levels, whereas products new to the market were relying more often on links to universities and research organisations at regional and national level. These findings are in line with the knowledge base concept, in the sense that incremental innovations are based more on synthetic knowlege drawn from partners in the value chain, whereas more radical innovations were more based on analytical knowledge drawn from universities and research. There are also two studies on the ICT sector in Austria that rely on the same data base as the present paper. The first one (Tödtling, Grillitsch, and Höglinger 2012) had a similar research question than the 2009 paper but was more oriented on differences between the regions investigated. The second study (Grillitsch, Tödtling, and Höglinger 2013) was particularly interested in the question if the *variety* of knowledge sources at each of the three levels (regional, national and international) matters for innovation performance. Variety was measured by number of different types of knowlege sources used by firms at a particular spatial level. The findings have demonstrated that knowledge variety at both regional and international levels indeed mattered for innovation performance. What was not investigated and tested, however, in these previous studies is if *particular combinations* of *knowlege sources and of spatial levels* respectively are relevant for innovation performance which is the focus of the present paper.

Summing up the literature review, we find much evidence of an increasingly complex and dynamic nature of the knowledge- and innovation process:

- At the firm level it relies on different types and combinations of knowledge and capabilities (internal/external, tacit/codified),
- There are sectoral patterns of dominant knowledge bases, but also evidence of their combination,
- This implies also specific patterns of dominant knowledge sources and innovation networks. These to some extent follow sectoral patterns, but are also shaped by the characteristics of RIS and NIS. Also these knowledge sources are usually of a combinatorial nature, i.e. firms combine sourcing from clients and suppliers, with links to universities and research.
- From a geographical perspective we find intense knowledge relations on several spatial scales and territorial levels, from local and regional, to national, European and truly global.
- And we find statistically significant relationships between specific types and levels of knowledge sources and innovation performance of firms.

We have, thus, substantial evidence on knowledge processes, sources and innovation patterns that partly follows knowledge base and innovation systems logics. In some of the literature reviewed we have also arguments and evidence for the combination of knowledge bases and respective sources. There are research gaps, however, regarding the following questions:

What is the role of *combinations* of knowledge for the innovation performance of firms? More specifically,

- How do firms combine different knowledge sources and –competencies in their innovation processes? and
- Which of these combinations matter most strongly?

It is these questions that will be adressed in the following sections.

3 Empirical Study: The ICT sector in three Austrian regions

We have investigated these questions empirically for the ICT sector in regions of Austria relying on a survey conducted in 2008/2009. The sample comprises 110 ICT firms located in the regions of Vienna, Upper Austria and Salzburg. For more background to the selection of firms and and regions, and also for descriptive findings see Tödtling et al. (2012). The firms were interviewed about their innovation processes and knowledge sourcing activities using a standardised questionnaire. We have published findings from this data base already in earlier studies, as was indicated in the literature review. However, in the present paper we have applied a new approach of analysing the data by focussing on the role of knowledge combinations for the innovation performance of firms. By applying this new analytical perspective we arrived also at new findings of relevance for this underresearched topic.

Since we were not able to measure directly the use of knowledge base combinations we have focussed on the external acquisition of knowledge by firms investigating (1) types of organisations/partners used and spatial levels of sourcing knowledge for innovation, and (2) patterns of labour recruitment: i.e. from which types of organizations did firms acquire new qualifications and skills in the innovation process? Organisation types analysed include universities, technical institutes and related firms representing different knowledge domains and –bases (Aslesen and Freel 2012; Strambach and Klement 2012). We were particularly interested in the combination of acquiring knowledge from respective organization types and spatial levels that are shown descriptively in tables 1-4. In addition to these external knowledge relations we were also interested in and controling for the internal capabilities of searching, exploring and integrating external knowledge into the firm. Here we used competencies in product and process development as indicator for analytical and synthetic knowledge, and competencies in design as indicator for symbolic knowledge of the investigated firms.

The next sub-section will analyse descriptively how firms combine different knowledge sources and competencies. This will be complemented in the proceeding sub-section by a multivariate analysis in order to explore which of the combinations is most strongly associated with different types of innovation outputs.

3.1 Combinations of knowledge sources and competencies

One approach to operationalise combinatorial knowledge is to investigate to what extent firms are sourcing knowledge for innovation from organisations and partners that represent different knowledge domains and –bases such as universities, technical institutes and related firms (i.e. suppliers, clients and competitors). External knowledge sourcing has been seen as a key mechanism to complement in-house knowledge (Powell and Grodal 2005; Tödtling, Lehner, and Trippl 2006; Gulati 2007; Giuliani 2007; Harrison et al. 2001; Graf 2006). It has also been argued and shown that successful sourcing of external knowledge requires a certain level of in-house capabilities to search, acquire and integrate such external knowledge (Cohen and Levinthal 1990; Hansen and Birkinshaw 2007; Zahra and George 2002). This implies that firms, sourcing for instance knowledge from universities, are expected to possess certain in-house capabilities and analytical knowledge that allow them to benefit from such interactions. From this perspective, the sourcing pattern is not only a proxy for the type of knowledge firms acquire externally but also an indicator for the knowledge bases internally used by firms. Aslesen and Freel (2012) show that firms in sectors dominated by an analytical knowledge base have a higher likelihood to collaborate with universities. In contrast, firms in sectors dominated by a synthetic knowledge base have a higher frequency of collaborating with related firms. Firms in symbolic industries source knowledge to a larger extent from other firms such as suppliers while using universities to a lesser extent as compared to firms in analytical industries. As indicated above, we distinguish here between sourcing from universities, technical institutes and related firms, which includes clients, competitors and suppliers. Table 1 shows how firms combine knowledge sourcing from these different types. 34% of the firms combine sourcing from universities and related firms while 33% interact with related firms only. 17% of the firms do not source knowledge from any of these types. The other categories are less frequent.

Table 1 Combination of knowledge sources used

Type	Frequency	Percent
Non mentioned	19	17
Related firms only	36	33
Technical institute and related firms	3	3
University only	4	4
University and related firms	37	34
University and technical institute	3	3
All types	8	7
Total	110	100

The literature review has also shown that firms acquire and combine knowledge from different geographical scales and that this pattern might have an influence on innovation performance (Tödtling, Grillitsch, and Höglinger 2012; Tödtling, Lehner, and Kaufmann 2009). Firms that are able to source knowledge from several spatial levels (regional, national, international), are said to be more innovative and less prone to “lock-in” (Grabher 1993; Hassink and Shin 2005). As discussed in the conceptual section, the spatial level of knowledge interactions has implications on the quality of knowledge exchange. Interactive and collaborative learning is facilitated by co-location (local and regional level) because of the partly tacit nature of knowledge (Polanyi 1958, 1966) and its embeddedness in social, cultural and institutional contexts (Gertler 2003). Also the ease of face-to-face meetings, and the spatial bias of social networks (Agrawal, Cockburn, and McHale 2006; Breschi and Lissoni 2009) support localised learning processes (Malmberg and Maskell 2006). On the other hand, specialised relevant knowledge is often located at higher spatial scales. Evidence has shown that e.g. value chains are frequently highly international (Dicken 2011, Coe and Hess 2011). Important clients and suppliers, who usually are key partners in innovation processes, consequently are often outside the region. The same applies for highly specialised knowledge providers such as research organisations in particular fields, and consultants (Tödtling, Lehner, and Trippl 2006; Tödtling, Grillitsch, and Höglinger 2012). In particular, analytical knowledge is assumed to travels easier across space due to the higher degree of codification. In sectors typically dominated by an analytical knowledge base, the innovation networks of firms, therefore, tend to have a more extended and international reach (Martin and Moodysson 2013; Aslesen and Freel 2012). The geographical pattern of knowledge sourcing, thus, indicates to what extent firms are embedded in regional, national or international networks of formal or informal nature. Often, such professional and social ties persist even after collaborations have formally ended (Owen-Smith and Powell 2004). Overall, therefore, the combination of knowledge sourcing from different geographic scales is assumed to be more benefitial for innovation than focussing on one level only.

Table 2 depicts how firms combine the sourcing of knowledge on different geographical scales. Interestingly, most firms (26%) source knowledge on all geographical scales. This is a strong sign for the multi-scalar nature of innovation interactions (Tödtling, Asheim, and Boschma 2013; Crevoisier and Jeannerat 2009). The second most frequent combination is the use of national and regional sources (17%). These are firms having a more restricted spatial horizon, relying on the regional and national innovation systems. 10% of the companies source knowledge only at the regional level and the same frequency was observed for sourcing at the international level only.

Table 2 Combination of knowledge sourcing at different geographical scales

Types	Frequency	Percent
No knowledge sourcing	18	16
Regional only	11	10
National only	5	5
National and regional	19	17
International only	11	10
International and regional	10	9
International and national	7	6
All levels	29	26
Total	110	100

As regards recruitment of qualified labour, the study distinguishes between universities, colleges, the same sector and other sectors as potential sources. Firms have indicated how important these organisations are for the recruitment of highly skilled employees. Since these are key carriers of knowledge and skills, the importance given to specific organisations indicates the acquisition of "embodied" knowledge of particular kind (e.g. scientific, applied, market oriented), as well as respective in-house capabilities. In the Austrian higher education system, universities provide academic and scientific training while colleges focus on transferring applied skills. In the field of ICT, these applied skills relate for instance to programming but also to design and multimedia. Hence, firms can acquire synthetic and symbolic knowledge embodied in recruits that were trained by colleges. Recruitment from universities indicates a higher importance of analytical knowledge. In contrast, recruitment from the same sector implies that firms source mainly industry specific knowledge, which, in the ICT sector, is predominantly synthetic. Recruitment from other sectors was seldomly mentioned as being important and is therefore not considered in the analysis of combinations. As shown in Table 3 most commonly (30%) firms emphasise the importance of recruitment from universities and colleges. 21% of the firms consider recruitment from their own sector only to be important. 14% of the firms have responded that all sources are important and equally many the opposite, i.e. that none of the recruitment sources is important. The other categories and combinations can only less frequently be observed.

Table 3 Combination of recruitment sources for qualified labour

Type	Frequency	Percent
Not important	15	14
Sector only	23	21
College only	8	7
College and sector	11	10
University only	3	3
University and sector	2	2
University and college	33	30
All three sources	15	14
Total	110	100

In-house competencies are expected to support the search and acquisition of respective external knowledge (Cohen and Levinthal 1990; Zahra and George 2002). The dataset includes several variables that relate to types of in-house knowledge and -capabilities. Firms were asked to indicate on which competencies their competitiveness rests. The predefined categories comprise specific competencies in design, product or process development, standardised production, production of tailor-made products, and marketing. All five categories were analysed but only two of these, design and product or process development, have turned out as significant in the multivariate analysis. For this reason, we only include these categories here. Design is an indicator for symbolic knowledge while product or process development indicates a mix of analytical and synthetic capabilities. Table 4 shows how firms combine these competencies. 29% of the firms rely on product & process development while just 10% focus on design competencies only. No fewer than 28% of the companies combine the two for achieving competitive advantages. Every third firm has no such advantage based on design or product & process development.

Table 4 Combinations of firm competencies

Combinations	Frequency	Percent
None of these indicated	36	33
Product or process development only	32	29
Design only	11	10
Design and product or process development	31	28
Total	110	100

3.2 Multivariate analysis: Which combinations matter?

The multivariate analysis is conducted for two different dependent variables: i) product innovations new to the market, and ii) the variety of different innovation types that a firm has generated. These two variables are chosen because combinatorial knowledge should matter in particular for these types of innovation. Innovations new to the market are presumed to be more radical than products new to the firm only. Market, in this context, relates to the ICT sector and is in principle global. Following the conceptual discussion, especially the generation of radical innovations requires the combination of different types of knowledge. 68% of the surveyed firms introduced product innovations new to the market (87% have introduced product innovations new to the firm). The second construct to measure innovativeness relates to the variety of innovation activities captured as count variable of the number of different innovation types that are generated by the interviewed firms. Firms engaging in several types of innovation activities presumably need to combine different types of knowledge to a larger extent than firms that only generate one specific type of innovation. Table 5 presents the distribution of firms according to their innovation variety. 27% of the firms generated two types of innovations, 25% three types of innovations and 20% one type of innovation. Firms with four or five innovation types were observed less frequently. Almost all firms produced at least one type of innovation.

Table 5 Distribution of firms by innovation variety

Number of innovation types	Frequency	Percent
0	2	2
1	22	20
2	30	27
3	28	25
4	18	16
5	10	9
Total	110	100

The models show the relationships between these innovation indicators (dependent variables)and i) combinations of sourcing knowledge from different partner types, ii) combinations of knowledge sourcing at different geographic scales, and iii) combinations of recruitment from different sources as independent ones (see previous sub-section). Design activities and product or process development competencies of firms were used as controls to capture the impact of in-house knowledge bases, besides other control variables such as the asigned importance of in-house knowledge, the service orientation of companies, and firm size. The models were run with additional controls (e.g. the share of R&D employees, whether firms have a R&D department, and the firms' location in Vienna, Linz, Salzburg or outside the urban areas). These, however, were not significant, did not affect the findings, and are thus not reported.

The regressions on product innovations new to the market apply a logit estimator. Innovation variety, in contrast, constitutes a count variable for which a poisson estimator is suitable if the assumptions are met (Wooldridge 2002). Test for zero-inflation and overdispersions were made. Also, the standard deviation for innovation variety (1.28) is below its mean (2.62). Despite the relative small sample size, there are significant results, which provide evidence for the importance of knowledge combinations for innovation. However, this study is restricted to one industrial sector in Austria and therefore complementary research of both quantitative and qualitative nature is required to fully understand the role and importance of knowledge combinations for innovation in a broader sense.

3.2.1 Models for product innovation new to the market

Product innovation and the combination of types of knowledge sources

Table 6 presents the results for the relationship between product innovations new to the market and the combinations of sourcing external knowledge from different partner types. In our study we find three dominant patterns of knowledge sourcing (see Table 1): i) firms that source knowledge from the sector only, ii) firms that source knowledge from universities and related firms, and iii) firms that source from all partner types (although this is less frequent). The model shows that firms combining knowledge from universities with knowledge from related firms have approximately 5 times higher odds of being innovative than firms that don't use such sources. Such firms typically combine analytical knowledge from universities with predominantly synthetic, sector-specific knowledge from related firms. The relationship for firms collaborating with all three partner types is not significant whereas the odds ratio is higher than for firms combining sourcing from universities and related firms. One reason for the low significance might be purely statistical as sourcing from all types of partners is a less frequent event and therefore a larger sample may be required to receive statistically significant results. The finding might also be due to the fact that external sourcing is resource intensive and consequently firms combine the acquisition of external knowledge from different partners selectively. Sourcing knowledge from related firms only (i.e. dominantly synthetic knowledge) has the lowest odds ratio but is still significant at 10% level. Obviously, such knowledge from the business domain supports innovation, but lacks cognitive and other difference for enhancing more radical product innovation.

Table 6 Product innovation and the combination of types of knowledge sources

Products new to the market	Odds Ratio	Robust Std. Err.	P-value
Knowledge sourcing from			
Related sectors only	2.49	1.37	0.096
Universities and related sectors	5.13	3.54	0.018
Universities, technical institutes and related sectors	6.41	8.90	0.181
Controls			
Product & process development only	4.19	2.52	0.017
Design only	7.11	6.10	0.022
Design and product & process development	5.15	4.01	0.036
Employees	1.12	0.22	0.587
Manufacturing oriented	0.74	0.48	0.637
Importance of in-house knowledge	1.02	0.01	0.017
N			100
Pseudo R2			0.2086

Another interesting finding from the described models is the high relevance of in-housecompetencies. Firms tend to be more innovative if they have internal competencies in design or product & process development. In particular design has a high odds ratio of 7 (indicating the importance of symbolic knowledge), but also the combination of both competencies has a positive impact (odds ratio of 5). These findings demonstrate, thus, that the combination of different knowledge bases and domains matters both as regards the sourcing of external knowledge as well as respective internal competencies. It still has to be investigated to what extent specific firm-internal competencies support the sourcing and combination of firm-external knowledge from different domains as literature on internal absorption capabilities suggests (Cohen and Levinthal 1990, Nonaka and Takeuchi 1995, Zahra and George 2002). Since thee high importance of internal competencies applies to all of the models investigated, we will not discuss these findings any longer in the descriptions below.

Product innovation and the combination of spatial scales of knowledge sourcing

Innovations frequently require knowledge acquired from different spatial scale. As shown descriptively in Table 2, most firms combine knowledge from regional, national and international sources. Table 7 shows whether firms that combine the acquisition of knowledge from different geographical scales are more innovative. Firms that combine all three geographic scales (26% of firms: see table 2) have approximately 8 times higher odds of being innovative than firms that do not source knowledge from external partners. The odds ratio for firms combining the international with the regional level (9% of firms) is very high due to the fact that all but one of these firms has introduced product innovations new to the market. Hence, while a precise odds ratio would require a larger sample, the data provide evidence that in particular the combination of knowledge from regional and international sources (frequently supplemented by national sources) promotes product innovations new to the market. This is basically in line with literature on local milieu and global networks (Camagni 1991), local buzz and global pipelines (Bathelt et al. 2004) and on multiscalar knolweldge relations (Asheim et al. 2001, Tödtling et al. 2013). As it is argued there, local and regional levels are favouring interactive learning and knowledge exchange (Malmberg and Maskell 2006; Gertler 2003), but firms are facing a risk of lock-in if they focus on this level only (Hassink 2010; Camagni 1995). Knowledge from national, international and global sources can bring in new perspectives and needed specialised knowledge, and thus create an additional momentum for more radical innovation (Bathelt, Malmberg, and Maskell 2004). The results, therefore, support this theoretical argument that a combination of knowledge from different spatial scales, and in particular the combination of the regional and international level, is conducive for the innovation performance of firms.

Table 7 Product innovation and the combination of spatial scales of knowledge sourcing

Products new to the market	Odds Ratio	Robust Std. Err.	P-value
Knowledge sourcing			
Regional only	2.57	2.47	0.327
Regional and national	2.82	2.23	0.190
International only	1.63	1.23	0.515
International and regional	18.03	27.34	0.057
International and national	1.27	1.56	0.848
International, national and regional	8.07	6.24	0.007
Controls			
Product & process development only	12.09	8.94	0.001
Design only	8.54	7.12	0.010
Design and product & process development	7.08	5.35	0.010
Employees	1.03	0.18	0.885
Manufacturing oriented	0.54	1.18	0.336
Importance of in-house knowledge	1.03	0.01	0.008
N			105
Pseudo R2			0.2842

Product innovation and the combination of recruitment sources

Table 8 depicts the results for the combination of recruitment from different sources and their impact on product innovations. Firms have a clearly higher likelihood to generate product innovations new to the market if they combine recruitment from universities with recruitment from colleges. This combination is also the most frequent one (see Table 3). From universities, ICT firms usually acquire "embodied" scientific and analytical knowledge while from colleges firms predominantly source more applied synthetic or symbolic knowledge via the recruitment of respective personnel. In Austria, several universities focus on ICT relevant sciences while a variety of colleges cover information technologies and software programming as well as new media and design competencies that are of relevance for ICT firms. In addition, the combination of all three recruitment sources (i.e. including other firms in the sector) is positively related to the probability that firms generate product innovations new to the market. As the ICT sector is dominated by a synthetic knowledge base, recruitment from sector firms will help firms to acquire knowledge that relates to sector specific technological and/or market knowledge.

Table 8 Product innovation and the combination of recruitment sources

Products new to the market	Odds Ratio	Robust Std. Err.	P-value
Recruitment from			
Sector only	2.78	2.19	0.194
Colleges only	7.46	7.06	0.034
Colleges and sector	1.89	1.93	0.535
Universities and colleges	24.21	24.54	0.002
Universities, colleges and sector	10.95	11.72	0.025
Controls			
Product & process development only	12.32	8.69	0.000
Design only	18.88	18.13	0.002
Design and product & process development	17.06	16.32	0.003
Employees	1.03	0.23	0.880
Manufacturing oriented	0.61	1.05	0.444
Importance of in-house knowledge	1.03	0.01	0.032
N			105
Pseudo R2			0.323

3.2.2 Models for Innovation variety

In this section, we investigate to what extent specific knowledge combinations lead to a higher variety of innovation types. The latter is a much less used innovation indicator than for instance product innovations new to the market, which may be due to several reasons. First, innovation was traditionally measured by indicators relating in particular to technological product or process innovations, including patent measures. Only recently, more emphasis was given to other types of innovation (Asheim et al. 2011, Tödtling and Grillitsch 2013). Another explanation might be that product and process innovations are better understood than other types of innovation. However, the competitiveness of firms does not only depend on such technological innovations. Among other things, competitiveness may also relate to marketing innovations, including appealing designs and new channels of distribution, or organisational and strategic innovations. Furthermore, more radical product innovations often go along with other types of innovation such as new processes and organisational change (Christensen and Raynor 2003, Scott et al. 2008). However, the generation and introduction of different kinds of innovation is more complex than focussing on one type only. It can be expected, therefore, that the combination of knowledge from different domains and spatial contexts are furthering a high variety of innovation types.

Innovation variety and the combination of knowledge sources

Table 9 depicts the results for the relationships of the combination of knowledge sources and innovation variety. The findings are to some extent in line with the previous results. The most significant positive relationship (significant at 1% level) is observed for firms that combine knowledge acquired from related firms and knowledge acquired from universities. In addition, the other two patterns of knowledge sourcing, i.e. sourcing from related firms only and combined from all three types (universities, technical institutes and related firms), are significant at 5% level. The coefficient for firms combining universities & related firms, thus, is significantly higher than for firms that source knowledge from related firms only. As the combination universities & related firms is also the most frequently observed (34% of firms: see table 1), there is strong evidence for the importance of this knowledge source combination for the innovativeness of firms. A difference to the previous model for product innovation can be observed for the role of firm-internal competencies. While competencies in design or product and process development are both individually and combined positively related to product innovations, this applies only for the combination of these competences for innovation variety. Hence, firms that generate a high variety of innovation types tend to benefit from a combination of knowledge bases internally. Also, it is interesting to observe that the relative importance of in-house knowledge is not significant anymore. One possible explanation could be that the generation and introduction of multiple innovation types depends even more than product innovations alone on specific combinations of both internal and external knowledge.

Table 9 Innovation variety and the combination of knowledge sources

Innovation variety	Coef.	Robust Std. Err.	P-value
Knowledge sourcing from			
Related sectors only	0.283	0.135	0.035
Universities and related sectors	0.458	0.123	0.000
Universities, technical institutes and related sectors	0.377	0.162	0.020
Controls			
Product & process development only	0.120	0.114	0.291
Design only	0.025	0.142	0.858
Design and product & process development	0.455	0.115	0.000
Employees	0.021	0.022	0.334
Manufacturing oriented	0.004	0.075	0.962
Importance of in-house knowledge	0.000	0.001	0.873
Constant	0.407	0.182	0.025
N			100
Pseudo R2			0.0617

Innovation variety and the combination of spatial scales of knowledge sourcing

Table 10 presents the results for innovation variety regressed on the combination of spatial scales of knowledge sourcing. In line with the previous analysis on product innovation, the combination of knowledge sourcing from all three spatial scales is most strongly related to innovation variety (significant at 1% level). Since this is also the largest segment of firms in our sample (26% see table 2) there is strong evidence that multiscalar knowledge sourcing, and the different knowledge types that go along with it, enhance also innovation variety. Furthermore, we can observe that the combinations of the national and international scales as well as the regional and national scales are positively related to innovation variety at 5% level. Behind these findings could be different segments of firms that have introduced multiple innovations: Firms more embedded in the regional and national innovation systems on the one hand (i.e. smaller scales of knowledge links) and those that combine NIS links with international ones (i.e. more outward reaching firms). The first semgment is larger (17%), whereas the second comprises only 6% of the investigated firms (see Table 2). Different from the product innovation model, the combination of the regional and international scale is not significant here. While the coefficient is comparable to the other combinations of two spatial scales, the standard error is significantly higher. Hence, it may be due to the relatively small sample that this relationship has not turned out significant. However, overall the previous findings suggesting that the combination of sourcing knowledge from different spatial scales has a positive effect on innovativeness are confirmed.

Table 10 Innovation variety and the combination of spatial scales of knowledge sourcing

Innovation variety	Coef.	Robust Std. Err.	P-value
Knowledge sourcing			
Regional only	0.072	0.173	0.679
Regional and national	0.333	0.139	0.017
International only	0.225	0.174	0.198
International and regional	0.331	0.216	0.124
International and national	0.331	0.146	0.024
International, national and regional	0.446	0.128	0.000
Controls			
Product & process development only	0.185	0.111	0.096
Design only	-0.013	0.155	0.934
Design and product & process development	0.501	0.122	0.000
Employees	0.023	0.020	0.271
Manufacturing oriented	-0.030	0.085	0.721
Importance of in-house knowledge	0.001	0.001	0.594
Constant	0.385	0.187	0.039
N			105
Pseudo R2			0.0740

Innovation variety and the combination of recruitment sources

Finally, Table 11 shows the results for the impacts of the combination of recruitment sources on innovation variety. In contrast to the model with product innovations as independent variable, recruitment from sector firms only appears to be most strongly related to a high variety of innovation types. This is a rather surprising finding at first sight that requires further research. One possible explanation could be that the non-technological types of innovations such as organisational or strategic innovations benefit in particular from industry-specific synthetic knowledge that can be acquired by recruiting personnel from firms in the same sector. This form of recruitment is with 21% of firms rather important. At a significance level of 10%, also recruitment from all three types of sources (including universities and colleges) is positively related to innovation variety. This relationshp is expected, but the segment of this combination is smaller with 14% of companies. Interestingly, companies that combine recruitment from universities and from colleges (the largest group with 30%) do not show a higher probability for innovation vartiety. Again this differs from the product innovation model where this combination of recruitment turned out to be the most important one. Obviously, for achieving innovation variety (that includes also organisational and management innovations) the reliance on analytical knowledge is less important while knowledge from other firms in the sectors is crucial.

Table 11 Innovation variety and the combination of recruitment sources

Innovation variety	Coef.	Robust Std. Err.	P-value
Recruitment from			
Sector only	0.260	0.124	0.036
Colleges only	-0.127	0.151	0.401
Colleges and sector	0.179	0.134	0.182
Universities and colleges	0.107	0.123	0.387
Universities, colleges and sector	0.215	0.129	0.094
Controls			
Product & process development only	0.301	0.114	0.009
Design only	0.083	0.157	0.596
Design and product & process development	0.614	0.116	0.000
Employees	0.045	0.024	0.055
Manufacturing oriented	-0.050	0.078	0.520
Importance of in-house knowledge	0.000	0.002	0.852
Constant	0.436	0.166	0.009
N			105
Pseudo R2			0.0656

3.3 Conclusions

This paper contributes to the important theme of knowledge bases, geography of knowledge sourcing, and innovation. In particular we were interested in the role of combinatiorial knowledge for the innovation performance of firms as well as in the role of different spatial scales in this respect. The key argument is that it is the *combination* of knowledge bases (synthetic, analytical and symbolic) as well as of knowledge from different spatial and institutional contexts (regional, international and international) that enhances innovation and avoids "lock-in". Empirical evidence for this thesis, however, is scarce in the literature and represents a research gap. We have studied this topic and questions for the ICT sector in three regions of Austria by investigating the sourcing of knowledge as well as the recruiting of skilled personnell from different domains, i.e. related and sector firms representing applied synthetic knowledge, universities representing scientific and analytical knowledge, and technical institutes and colleges representing applied synthetic and symbolic knowledge, and by analysing combinations of these. We also investigated the acquisition of knowledge from sources at different spatial scales, i.e. regional, national and international (representing RIS, NIS and higher levels respectively), and combinations thereoff. Although the study has focussed on the combination of external knowledge sourcing there is a strong interrelationship with firm –internal knowledge and -competencies. On the one hand is the acquisition of external knowledge essential for innovation by complemeting firm-internal knowledge bases. On the other hand we find that certain internal competencies are needed in order to acquire and absorb external knowledge as the literature on absorptive capacity has shown.

Our study has demonstrated how common it is for firms to combine different sources of knowledge and of recruitment. The results provide also clear evidence for the multi-scalar nature of knowledge sourcing (Asheim et al. 2011, Aslesen and Freel. 2012, Tödtling et al. 2013). ICT firms in Austria most commonly use all geographical scales, regional, national and international, to acquire knowledge in their innovation processes. Moreover, of all possible *combinations of spatial scales*, firms sourcing knowledge from all levels have the highest likelihood to generate product innovations new to the market and tend to show also the highest variety of innovation types. The importance of combining knowledge from several geographical scales resonates very well the rich literature in economic geography. Geographic proximity supports interactive learning because of the sticky nature of knowledge (Asheim and Isaksen 2002; Nonaka and Takeuchi 1995; Von Hippel 1994; Malmberg and Maskell 2006), that has to do partly with the difficulty to transfer tacit knowledge over distance (Polanyi 1958), the social, cultural and institutional embeddedness of knowledge (Gertler 2003, 2004), and the spatial bias of social networks (Agrawal, Cockburn, and McHale 2006; Breschi and Lissoni 2009; Granovetter 2005). However, several strands of literature in economic geography strongly suggest that it is important to complement and combine local knowledge sourcing with sourcing from higher geographic levels in order to avoid lock-ins (Hassink 2010; Grabher 1993) and to create momentum to localised learning processes (Camagni 1995; Bathelt, Malmberg, and Maskell 2004; Tödtling, Grillitsch, and Höglinger 2012).

As regards the *combination of types of knowledge sources* that represent the different knowledge domains of business, science andapplied (technology) development, this study also provides strong evidence that firms are more innovative if they combine knowledge from such different domains. Most firms acquire knowledge from related firms, which is expected for a sector dominated by a synthetic knowledge base, where producer-user interactions (Lundvall 1988) and the DUI mode of innovation (Jensen et al. 2007) dominate. Approximately one third of the firms, however, combine this with the acquisition of knowledge from universities and these firms have turned out to be more innovative. Universities are a typical source for analytical knowledge while sector firms are predominantly sources for synthetic knowledge about markets and technologies, as this is the dominant knowledge base in the ICT sector. As the absorption of analytical knowledge from universities requires matching in-house capacities, it can be assumed that many of the firms combining universities and related firms as knowledge sources, also combine synthetic and analytical knowledge in-house (Aslesen and Freel 2012).

As regards, *recruitment*, however, the results are more mixed. Most commonly, firms consider both universities and colleges as important recruitment sources. As indicated above, universities are an important source for largely ”embodied” analytical knowledge. In contrast, Austrian colleges focus on transferring applied skills related to synthetic knowledge (e.g. programming), symbolic knowledge (e.g. design), or a combination of these (e.g. new media). This combination of recruitment from universities and colleges is most significantly related to the generation of product innovations new to the market. In contrast, recruiting from sector firms only and to a lesser extent recruitment from all three domains are predictors for innovation variety. It appears, thus, that non-technological innovations that are included in “innovation variety”, such as new marketing concepts, management tools or organisational structures rely more on knowledge from the business domain than on knowledge from universities and colleges.

Overall, this study provides strong support for the importance of combining different types of knowledge as acquired from different partners, at different geographic scales, and through recruitment from different sources. However, this study also suggests that further research is needed in particular to see how firms combine different types of firm-internal knowledge with different types of -external knowledge. Our research provides evidence that firm-internal competencies related to symbolic knowledge (design competencies) and analytical or synthetic knowledge (product and process development competencies) have a significant positive effect on the innovativeness of firms. However, in order to identify possible sources of synergies through the combinations of different types of firm-internal and fexternal knowledge, a larger survey covering several industries and with more detailed indicators for both firm-internal and firm-external knowledge bases would be required. Also, this study suggests that it could be of interest to focus besides product and process innovations also on other types of innovation, how these innovation types are related to each other and what implication this has for knowledge combinations.

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