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Patterns of knowledge use in 'low-tech' industries

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The innovativeness of low- and medium-technology (LMT) manufacturing firms in advanced economies has been the research focus of a growing body of literature since the beginning of the last decade. This paper reviews the main research findings and highlights the largely unresolved problem in LMT research of the contradiction between the presumed homogeneity of LMT sectors because of the formal category of 'low R&D intensity', and the heterogeneity of the same firms in LMT sectors. To overcome this problem, the paper proposes an empirical taxonomy of innovative LMT firms based on the dimension of knowledge. To sketch out this knowledge-oriented taxonomy, the paper uses the concept of the 'distributed knowledge base'. In this approach, four different patterns of knowledge use in LMT firms can be identified. This conceptual perspective has consequences for understanding the sources and directions of innovation strategies in LMT firms and the perspectives of LMT sectors pertaining in advanced economies, such as the EU. Additionally, specific recommendations on innovation policy can be inferred from these considerations that go beyond the current state of the art. Overall, this paper sums up some of the findings of past low-tech research, and reinterprets its central findings.

Introduction

The innovativeness of low- and medium-technology (LMT) industries in advanced economies has been the research focus of a growing body of literature since the beginning of the last decade. These industries may also be termed 'non-research-intensive and mature industries', as they are well advanced along their life cycles. In the manufacturing sector, LMT refers to such industries as household appliances, the food, paper, publishing and print industries, the wood and furniture industry, and the manufacture of metal products, textiles and plastic products. The research interest in LMT industries is motivated mainly by criticism of mainstream innovation research and innovation policy, which regards a high investment in R&D and advanced technologies as the key to growth and prosperity. This leads to an almost exclusive focus of many scholars and policymakers on economic sectors of high R&D intensity, while the economic importance and specific innovative ability of LMT industries is overlooked. In contrast to this view, LMT research as a whole has clearly shown that LMT firms and industries are by no means technologically and economically stagnant. LMT industries play a decisive role in shaping current economic structures and are essential to the future economic and technological development of advanced countries (Robertson *et al.*, 2009; Robertson and Jacobson, 2011).

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A number of problems remain. Foremost among these is that the LMT sector and LMT firms are differentiated solely by the formal criterion of R&D intensity below 3% (OECD, 2005), without any systematic factoring in of the heterogeneous structural conditions of the respective sectors and companies. LMT research has shown however that LMT firms manifest a distinctive heterogeneity; for example, with regard to their innovation strategies, knowledge base and technological level (e.g. Tunzelmann and Acha, 2005; Kirner *et al*., 2009a; Huang *et al*., 2010; Rammer *et al*., 2011; Som, 2012). Particularly, it cannot be assumed that all LMT firms, because of their low R&D-intensity, show identical innovation behavior based on a more or less homogenous non-R&D knowledge base. Despite findings which point to a considerable intra-sectoral heterogeneity of LMT industries, only a few studies have addressed this problem or presented taxonomies of innovative LMT firms that can identify regularities below the general sectoral level (e.g. Hirsch-Kreinsen, 2008; Köhler, 2008; Huang *et al.*, 2010; Som, 2012). Such taxonomies are an important step towards a more differentiated perspective on the direction of LMT innovation activities. However, their main interest is in the innovation behavior of LMT firms in general and, as will be shown, they do not focus on knowledge as the main determining factor in innovation.

Knowledge is a determining factor in innovation for several reasons. First, the overall starting point of LMT research is the aforementioned industry classification based on the relevant type of knowledge for innovative activities, as measured by R&D intensity (Hatzichronoglou, 1997; OECD, 2005). In the view of this classification, LMT industries are generally characterized as having a non-R&D-intensive knowledge base. The underlying assumption is that the knowledge base of LMT industries is relatively homogeneous. Second, the focus on knowledge as the determining factor is supported by the theoretical understanding of knowledge as the basis of technological change and as the determiner of innovation. The high relevance of knowledge has been instructively portrayed by innovation research. From this perspective innovation is conceptualized as a learning process driven by various types of knowledge originating in different societal and institutional milieus (e.g. Lundvall, 1988; Metcalfe, 1998; Lundvall *et al.*, 2002).

This paper proposes an empirical taxonomy of innovative LMT firms based on the dimension of knowledge and not on their sectoral affiliation. This knowledge-oriented taxonomy uses the concept of the ‘distributed knowledge base’, proposed by Robertson and Smith (2008), which can be regarded as a highly suitable approach for this task. This concept gives a multiple and multi-level perspective on the sources and the use of different types of knowledge by innovative LMT firms. From this conceptual view, this contribution develops a taxonomy of innovative LMT firms that encompasses the patterns of LMT innovation presented in the literature. Additionally, specific recommendations for innovation policy can be inferred that may advance the current state of the art.

Main findings of LMT research

A key aim of LMT research has been to assess the ability of LMT companies and industries to innovate.[1] In fact, researchers have questioned whether LMT companies are innovative at all. They have also investigated which specific paths to innovation they take and what conditions and what determinants are relevant to them. LMT research conducted during the last 10–12 years has followed a

sectoral perspective, guided by R&D intensity indicators. The term 'innovation' is conventionally understood as the application of better solutions that meet new requirements, unarticulated needs or existing market needs. This is accomplished through more effective products, processes, organizations or services. In other words, innovation activities encompass product- and process-related as well as technical and non-technical fields (e.g. Som, 2012, p.227).

Even though LMT studies are based on different research designs, datasets and categories, they converge convincingly in their general findings. They clearly demonstrate that LMT industries, in general, should be regarded as innovative. This is indicated by LMT studies of firms from the complete range of LMT industries across the whole of the EU (Bender and Laestadius, 2005; Tunzelmann and Acha, 2005; Arundel *et al.*, 2008; Hirsch-Kreinsen, 2008; Sáenz *et al.*, 2009; Huang *et al.*, 2010). The findings are the same for studies of specific LMT sectors, such as the forest industry (Palmberg, 2001; Chamberlin and Doutriaux, 2010), food processing (Menrad, 2004; Rama, 2008; Manniche and Testa, 2010), mechanical engineering (Schmierl, 2005; Chen, 2009; Freddi, 2009), and packaging and paper (Hansen and Serin, 1997; Ghosal and Nair-Reichert, 2009).

It is estimated that at least half of all innovative companies in Europe have no in-house R&D capacities (Arundel *et al.*, 2008; Huang *et al.*, 2010).[2] It is evident that LMT firms are less innovative than HMT firms (Heidenreich, 2009; Rotaba and Beaudry, 2009; Rammer *et al.*, 2011; Som, 2012). The European Community Innovation Survey (CIS) finds that, whereas only 37% of LMT firms were judged to be innovative in the middle of the last decade, the figure for HMT firms was over 55% (Heidenreich, 2009, p.486). Overall these findings also point to differences within the LMT sector. This is primarily a matter of the aim and focus of innovation activities of individual LMT firms, and therefore also of the divergent sources and types of knowledge relevant to their innovation activities.

Dominance of process innovations

Innovation research agrees on the importance of process innovation in LMT industries (Evangelista and Mastrostefano, 2006; Heidenreich, 2009; Kirner *et al.*, 2009b; Huang *et al.*, 2010; Rammer *et al.*, 2011). In Heidenreich's analyses of CIS data, process innovation is twice as important in innovating LMT companies (36%) as in innovating HMT companies (17%) (Heidenreich, 2009, p.486). Data from the German Manufacturing Survey (GMS) for 2008 largely corroborate these findings, pointing to the much greater importance of technical process innovations for innovative non-researching firms than for research-intensive companies (Rammer *et al.*, 2011, p.132). Yet only a small minority of these LMT firms can be characterized as pure technology adopters that take on ready-to-use new process technologies. The large majority conduct activities of integration and adaptation to new technologies in their manufacturing processes (Huang *et al.*, 2010). Organizational innovation measures are also important in this context, such as the introduction of new company systems or new sales and logistic concepts that are often directly linked to technical innovation processes. According to the available data, this type of non-technical innovation is as important as technology-based process innovation activities in LMT firms. In this regard, LMT firms do not differ significantly from HMT firms (*cf.* Heidenreich, 2009; Rammer *et al.*, 2011; Som, 2012).

Two particular factors attest to the importance of process innovations in LMT enterprises. First, process innovations can be carried out relatively smoothly, even in firms without their own R&D competencies, as the basic development is conducted by technology suppliers. The adoption of new machinery requires efforts on the part of the innovating LMT firm, such as the integration of the new technology into existing processes, reorganization measures and the retraining of employees (Rammer *et al.*, 2011, p.84). These adaptation activities usually take place within the context of ongoing operations and under the direction of production management (on the shop floor, in other words). Additional investments in in-house R&D activities are normally not required. Second, the considerable cost competition prevalent in LMT industries puts pressure on enterprises to concentrate their innovation efforts on production processes, as this allows them to cut costs quickly, improve their efficiency and so assure their competitiveness (Cox *et al.*, 2002; Kirner *et al.*, 2009a; Robertson and Jacobson, 2011).

By comparison, a similarly important role is ascribed to product innovation (Rammer *et al.*, 2011), even though product innovation plays a far greater role in HMT industries than in LMT industries. In Heidenreich's study of 26 member states of the EU, a little more than 18% of innovating LMT firms focus on product innovations, while the figure for HMT firms stands at more than 30% (Heidenreich, 2009, p.486; see also Arundel *et al.*, 2008). Data for Germany reveal a similar ratio (Rammer *et al.*, 2011, p.132). Thus far, research has offered few explanations for this. One can surmise that product innovation simply demands the use of new technologies to a far greater extent than process innovations (Huang *et al.*, 2010), calling for technology-oriented competencies and probably specialized R&D capacities which LMT firms often do not have (Hirsch-Kreinsen, 2008; Som, 2012). On the one hand, many LMT innovation activities focus only on the continuous development of existing products. Product components are often improved incrementally with regard to materials, function and quality to accommodate changing customer demands. On the other hand, product innovations can also include redesign as well as functional and technological upgrading. These measures are often closely connected with organizational and market-oriented process innovation. With these innovations, non-research-intensive companies aim to react quickly to changing customer preferences and may attempt to create new sales segments by particular branding strategies, such as the introduction of trademarks for LMT products and additional service offers. Researchers regard service innovations as having an important role in LMT companies (Kirner *et al.*, 2009a; Improve, 2011; Mamede and Fernandes, 2012).

Multiple knowledge sources

The availability of knowledge and access to knowledge sources pertinent to innovation constitute key dimensions of LMT research. In-house sources of information are highly important for innovation in 40.6% of all innovating LMT firms, according to CIS data. However, for HMT firms the importance of in-house information sources is markedly higher (55% of innovating firms). This is evidently because of the in-house R&D capacities at their disposal (Heidenreich, 2009, p.488). These research findings are corroborated by analyses of other data for the EU (Arundel *et al.*, 2008; Huang *et al.*, 2010) and for Germany (Rammer *et al.*, 2011).

Given their lack of R&D capabilities, formal knowledge generation plays an insignificant role in LMT firms. Instead, innovation activities proceed in the form of 'practical and pragmatic ways of doing and using' (Tunzelmann and Acha, 2005, p.417), requiring 'application-oriented practical knowledge' (Arundel *et al.*, 2008; Hirsch-Kreinsen, 2008). This encapsulates a complex bundle of different knowledge types: explicit, codified and formalized elements, such as design drawing and requirement specifications for new products and, more significantly, implicit elements, such as accumulated experience and established, tested and proven routines for solving technical problems. An example of this is process innovation activity (Rammer *et al.*, 2011). On the one hand, enterprises use engineering knowledge already incorporated into production facilities and codified in operating manuals. On the other hand, they are forced to develop specifications and ongoing intervention and adaptation measures. An indispensable precondition for this is the knowledge available on the shop floor; for instance, about the shortcomings of production technologies currently in use, or about innovation needs (Ghosal and Nair-Reichert, 2009).

Research also reveals that external knowledge plays a greater role in LMT innovation than in-house knowledge. One of the main reasons for this is that LMT firms can compensate for their lack of R&D resources by adapting externally-generated knowledge (Bender and Laestadius, 2005; Robertson and Smith, 2008; Hauknes and Knell, 2009). Empirical findings suggest that this external knowledge is the main source of generated knowledge for LMT companies (Robertson and Patel, 2007). It is not surprising, then, that market- and sales-related information from customers and competitors is a very important driver of LMT innovation (Grimpe and Sofka, 2009; Heidenreich, 2009; Rammer *et al.*, 2011). Data from 20 EU countries indicate that more than 35% of all innovating LMT firms regard these information sources as highly important (Heidenreich, 2009, p.489). More detailed research emphasizes that customer input is particularly significant for product innovation. According to CIS data, this is so for around 24% of innovating LMT firms (Heidenreich, 2009, p.489).

Because of the importance of process innovation, knowledge provided by suppliers also plays a greater role in LMT than in HMT innovation (Cox *et al.*, 2002; Heidenreich, 2009; Rotaba and Beaudry, 2009; Rammer *et al.,* 2011). About 25% of all LMT firms consider this source of information extremely important (Heidenreich, 2009, p.489). This type of knowledge usually involves machines and other technological components; it is embodied knowledge (Arundel *et al.*, 2008). In contrast, scientifically-generated and codified knowledge is less important to LMT innovation. Although research points to the importance of a whole range of non-company organizations, such as research institutes, universities, consulting firms and trade fairs as providers of information, LMT studies indicate that HMT firms make much more intensive use of such sources than LMT firms (Grimpe and Sofka, 2009; Kirner *et al.*, 2009b). In Heidenreich's analysis of the CIS data, 6.2% of all HMT firms, as opposed to only 3.2% of all LMT firms, think of the scientific domain as an important source of information (Heidenreich, 2009, p.489).

Analyzing the heterogeneity

State of the art and open questions

Overall, the findings presented above suggest considerable heterogeneity in LMT sectors in terms of innovation patterns and knowledge bases. However, most studies do not discuss the conceptual consequences stemming from these findings. Rather,

they equate LMT firms with LMT sectors, implicitly assuming a uniformity in LMT industries and sectors. They assume that conclusions can be drawn as easily about an entire sector as about an individual firm. In the words of Paul Robertson (Robertson *et al.*, 2009, p.442), such conclusions fall 'into the trap of equating low-technology industries or sectors with low-technology firms'.

Thus far, only a few LMT studies have explicitly broached this issue, broadening the perspective of LMT research by introducing a more comprehensive understanding of industrial innovativeness (e.g. Tunzelmann and Acha, 2005; Kirner *et al.*, 2009a; Huang *et al.*, 2010; Som, 2012). On the one hand, they agree with the mainstream position in LMT research that high R&D intensity cannot automatically be equated with high innovativeness, and that non-R&D-based knowledge can be highly relevant to successful innovation. On the other hand, they approach critically most LMT studies and the unresolved heterogeneity issue, while underscoring especially that LMT sectors comprise a considerable variety of high-, medium- and low-tech firms, and that general statements about a clearly definable sector that appeal to the link between R&D intensity and innovativeness may be compromised by the simple fact of intra-sectoral heterogeneity (Kirner *et al.*, 2009a, p.447).[3]

Some studies opt for an analysis primarily focusing on the micro-level of individual companies in order to identify differences and similarities in innovation behavior and, more or less explicitly, the various knowledge bases of LMT companies. Methodologically, these studies focus on the definition of types or patterns. In doing this, the authors follow a longstanding tradition in innovation research. Taxonomies of innovative firms have been widely applied to reduce the complexity of empirical phenomena, to systematize, and thus to understand better the diversity of innovation patterns in firms and sectors (see de Jong and Marsili, 2006). Some LMT taxonomies are based on case study research. On this empirical basis, Hirsch-Kreinsen (2008) and Köhler (2008) distinguish between several relatively similar types of LMT innovation strategies. Hirsch-Kreinsen identifies three different innovation strategies that he terms 'step-by-step product development', 'customer-oriented' and 'process specialisation' (Hirsch-Kreinsen, 2008). Similarly, Huang *et al.* refer to three different LMT innovation types. On the basis of an analysis of CIS data, they differentiate among 'technology adopters', who acquire new technologies from outside; 'non-R&D innovators', who conduct non-R&D-based innovative activities in-house; and 'contract R&D performers', who contract external R&D activities (Huang *et al.*, 2010). Also focusing on conceptual considerations, Arundel *et al.* (2008) outline various LMT innovation methods, such as 'technology adoption', 'minor modifications', 'imitation including reverse engineering' and 'combining existing knowledge in new ways'. Overall, these studies focus primarily on the strategies or modes of innovation, their key areas and main targets.

A methodologically more sophisticated study is doubtless that by Som, who distinguishes among five low-tech innovation patterns (Som, 2012, p.317): 'knowledge-intensive product developers', 'customer driven, technical process specialists', 'occasional business-to-customer (B2C) product developers', 'low-innovative, labour-intensive manufacturers' and 'volume-flexible, specialised suppliers'. The study is based on a cluster analysis of GMS data from German industry, and a specific focus on a sample of non-R&D-performing firms. It presents a detailed and differentiated picture of low-tech innovation patterns. However, these patterns are broadly designed and it is not very clear what types and sources of knowledge are relevant to the respective innovation patterns.

The concept of patterns of LMT knowledge use

To arrive at a more systematic view of knowledge as the main precondition of innovative LMT firms, this paper prefers the concept of the 'distributed knowledge base', presented by Robertson and Smith (2008). This concept gives relevant hints as to how LMT innovation can be traced back to different sources of knowledge at the micro- and macro-levels. Robertson and Smith define the term 'distributed knowledge base' as a set of 'knowledges' and knowledge sources maintained across an economically and socially integrated network of agents and institutions.

The authors distinguish among three areas of innovation-relevant knowledge. The first of these is 'firm-specific knowledge', which is linked to specialized product characteristics in firms with one or a few technologies they understand well and which form the basis of their competitive position. This knowledge area can also be termed 'local knowledge', which comprises codified elements such as handbooks, formal organizational rules and technical process protocols, and is characterized by some degree of tacitness (Bender and Laestadius, 2005, p.137; see also Rip, 1997). The second knowledge area is defined as 'sectoral and product-field-specific knowledge', characterized by such features as shared intellectual understanding of technical functions, performance characteristics, use of materials, and so on. Following Robertson and Smith further, one can say that part of the industrial knowledge base is public, and that it is a body of knowledge and practice which influences the performance of all the firms in an industrial sector. This body of knowledge is developed, maintained and disseminated by institutions and company-external organizations of various kinds. The notion of knowledge area shows similarities to the knowledge perspective of the sectoral system approach (Malerba, 2005). The third knowledge area Robertson and Smith call 'widely applicable knowledge bases', of which the most important is the general scientific knowledge base. This knowledge area can also be thought of as 'global knowledge', as it refers to existing technological paradigms and is, in principle, highly mobile (Bender and Laestadius, 2005, p.136).

With these categories in mind, one can differentiate between several levels and types of knowledge relevant to LMT innovation, and examine the heterogeneity of the LMT sector. The taxonomy of patterns of LMT firm knowledge use can be specified. Each pattern represents a specific combination and expression of the various areas of innovation-relevant knowledge. The patterns are determined by the most influential or innovation-determining knowledge area, and by less important or complementary knowledge areas. Additionally, the various access mechanisms whereby LMT firms gain firm-external available knowledge, and the innovative outcome of the respective pattern of knowledge use, are taken into consideration. Conceptually, these patterns represent distinguishable types of knowledge-based opportunities and determining factors for innovation in LMT industries. Empirically, however, the patterns are not exclusive to each other and may overlap. Their function is to describe and explain similarities and differences among the driving factors and courses of innovation in LMT industries. In other words, they should lead to an understanding of factors determining firm behavior and directions of innovation in LMT industries. Ultimately, they may inform policy for these industries.

Methodological considerations

The definitions of these patterns are based on a reinterpretation of the findings of previous studies. Here the findings are analyzed in a new and different way, focusing

on the knowledge dimension. The guiding question is: where does the relevant knowledge come from? This reinterpretation is based on case study research, especially that of Hirsch-Kreinsen (2008) and Köhler (2008), which provides relatively deep insights into the conditions and mechanisms of LMT innovation and therefore allows a more precise identification of the types and sources of relevant knowledge. It is also dependent on LMT innovation taxonomies based on statistical data, either from CIS (Arundel *et al.*, 2008; Huang *et al.*, 2010) or the German GMS dataset (Som, 2012).

In estimating the importance of knowledge types and sources in the reinterpreted empirical findings, the direct statement of the authors and their assessments of their empirical findings were the main indicator. A comparative cross examination of the various interpretations and findings and their plausible interpretation was a secondary indicator. Basically, the patterns of knowledge use should be regarded as empirical types. Their development is empirically-driven, but also guided conceptually by the analytical framework.[4] One of the statistically-based studies (Som, 2012) deviates slightly from the usual LMT definition. To avoid any definition problems, especially demarcation problems between low-tech and medium–high-tech firms, LMT firms are defined as non-R&D-performers (i.e. firms that do not have in-house R&D). This relatively strict definition may lead to an underestimation of internally-created R&D-based knowledge in LMT firms in general. However, it can be assumed that internal R&D capacities play a minor role anyway, and this definition does not exclude knowledge impulses from external R&D organizations.

Patterns of knowledge use

Market-based knowledge use

Four typical patterns of knowledge use of LMT firms can be sketched out. The first can be termed 'market-based' knowledge use. It is characterized by a strong customer- and market-orientation of the innovating firms. Knowledge of the market is the determining factor for the innovation activities of these firms. Such knowledge is occasionally complemented by the selective use of knowledge from external R&D organizations. This is new knowledge on promising product designs and new marketing strategies, or engineering expertise and experience in the design of new processes and equipment. The knowledge of market structures and customer preferences is normally generally available to all companies in the form of studies, general marketing knowledge and trade fair presentations. The same is true for the relevant technological or marketing knowledge that is generally readily available as codified knowledge. Hence, this type of knowledge can be characterized as a combination of sector- or product-field-specific knowledge and widely applicable knowledge. The first one refers mostly to the sectoral and product-specific market situation, whereas the latter is an element of the globally-available scientific knowledge base.

The companies access these externally-available knowledge sources in various ways. Organized sales negotiations with customers, in which the specifications of products are decided, play an important role. Lengthy and cooperative relations with lead users and to lead producers in supply chains are also important. An instructive example of this is the case of a Spanish dairy producer. Flexible, customer-specific product development is the main profit source of this firm. Together with a large multinational company from the food processing sector, it developed a cholesterol-reducing dairy product (Köhler, 2008, p.14). The successful use of sector-specific

and global knowledge by LMT firms depends complementarily on the firm-specific local knowledge base and the related transfer abilities of the companies. This local knowledge base is shaped especially by application-oriented practical knowledge, the importance of which can be attributed to the lack of in-house R&D capacities and systematic structures for innovation processes (*cf.* Tunzelmann and Acha, 2005; Hirsch-Kreinsen, 2008).

The innovation activities of these companies include product, process and service innovation. Usually they develop their products incrementally in response to customer demand or specification. Likewise, process and service innovations are geared to given sales situations with the aim of improving the flexibility and delivery capacity of the companies and of boosting their customer relations by means of additional service offers. These market knowledge-based innovation activities can also include the pure replication or imitation of products and processes already available (Arundel *et al.*, 2008). Examples of this pattern of knowledge use are company activities in textile and clothing industries as well as furniture and leather-goods manufacturers, whose product development is geared to anticipated fashion cycles and whose existing product lines call for continuous variation. Other examples can be found in the food and beverage industry with its prevailing small and medium-sized enterprises producing flexibly for specific market segments (Menrad, 2004). Focused on the micro-level of individual firms, this knowledge pattern includes firm strategies termed 'customer-oriented' (Hirsch-Kreinsen, 2008) or 'customer-driven, technical process' (Som, 2012). The firms considered here can also be characterized as typical 'non-R&D innovators' (Huang *et al.*, 2010).

Supplier-based knowledge use

The second type of LMT pattern can be termed 'supplier-based knowledge use'.[5] It is characterized by the significance of external suppliers as main knowledge sources for the innovation activities of firms. This knowledge base is available as knowledge embodied in machinery as well as in codified form in terms of formal organization rules, instruction handbooks, management concepts, checklists etc. In conjunction with, and complementarily to, these external knowledge sources, the local knowledge base of the firms plays an important but subordinate role as the firms act as technology adopters (Huang *et al.*, 2010) or adapt the global knowledge to their respective company conditions by means of additional specifications. The adoption of new machinery requires effort on the part of the innovating LMT firm, such as the integration of the new technology into existing processes, and the reorganization or the retraining of employees (Rammer *et al.*, 2011). These adaptation activities usually take place within the context of ongoing operations on the shop floor. At the local firm level, application-oriented practical knowledge and accumulated experiences of bottlenecks and the needs of the manufacturing processes are of major significance for the implementation of new process technologies. Following the categories of Robertson and Smith (2008), this can be termed a 'widely applicable knowledge base', including scientific knowledge as well as application-oriented engineering knowledge.

There is little research evidence on the prevailing mode of access of LMT firms to the external body of knowledge. General data indicate that cooperative relations with suppliers are seen as crucial for innovation activities (Rammer *et al.*, 2011); however, it may be surmised that cooperation with suppliers is important only to

those LMT firms which need specific adaptations of globally available technologies. Thus, the innovation undertaken on this basis is primarily process innovation. The empirical findings show that these process innovations often go hand in hand with the deployment of innovative organization and management concepts. Under these technical and organizational circumstances, the safeguarding and constant improvement of the product quality is achieved as a quasi by-product. The main objective of process innovation is the continuous improvement in the company's efficiency in order to increase competitiveness.

As the research findings show, these enterprises belong to industrial subsectors which tend to manufacture their products using automated methods and integrated process technologies. Firms in the furniture industry are an instructive example of this. A second example is the continuous development of processes in woodworking firms, which have achieved a high level of process performance and process precision. Similar trends can be discerned in sheet-forming companies and firms manufacturing plastic parts, mechanical components and aluminum parts. Paper manufacturing and the food processing industry, with its many intricate processes, are other examples of this high-level knowledge pattern. Apart from processes with a high level of technology and automation, the innovation activities of this pattern also comprise processes involving relatively simple, standard techniques which are continually cultivated. LMT research calls firms with this knowledge pattern 'process specialists' and 'volume-flexible specialized suppliers' (Som, 2012), and confirms that these innovation strategies are very frequently found in LMT sectors (Arundel *et al.*, 2008).

Firm-specific knowledge pattern

The 'firm-specific knowledge' pattern is characterized by the prevalence of firm-specific local knowledge, which is the result of systematic, continuous widening of the internally-available knowledge stock. An indispensable element of this pattern is the practical knowledge gained from practical solutions found to the shortcomings and problems involved in the application of production technologies. Innovation occurs in the context of production and is initiated and pursued by such staff as engineers, technicians, master craftsmen and qualified workers. In conjunction with these firm-internal sources of knowledge, external knowledge sources, such as engineering-oriented research institutes and other specialized research organizations, play a complementary role as knowledge sources for innovation activities. This type of knowledge includes firm-specific knowledge linked to very specialized technological characteristics of firms, and widely applicable knowledge bases, especially application-oriented engineering knowledge.

This ability to utilize locally available knowledge is dependent on the routines and structures of the company organization; for instance, the division of labor, the prevailing communication and cooperation forms, and related skills and personnel structures. In some firms with this pattern, management intervenes by giving these development projects strategic priority and setting target agreements with engineers and master craftsmen. In other cases, as in fashion-oriented clothing manufacturers, established procedures generate product ideas within the context of the existing production process. There are also many cases of innovation ideas resulting from random trial and error, and from the ideas of individual managers, technicians or salespeople. Personnel and organizational conditions crucial for the effectiveness of

these practices include open channels of communication, room to maneuver, and slack time, but also the impetus from management that promotes mobilization of available knowledge (Hirsch-Kreinsen, 2008).

Many of these firms belong to the industrial subsectors 'fabricated metal products', 'wood products and furniture' and 'machinery and equipment'. These firms are often suppliers to the automotive industry, which not only produces minor parts, but also rather complex components. Hence, the firms with this pattern are also referred to as 'volume-flexible, specialized suppliers', characterized by a limited degree of innovativeness. Their strategy is 'continuous further development of given products' (Hirsch-Kreinsen, 2008, p.24). This kind of innovation behavior can also be seen as combining existing knowledge in new ways (Arundel *et al.*, 2008, p.320).

R&D-based knowledge use

'R&D-based knowledge use' in LMT industries might be regarded as a contradiction in terms. However, this category is used to subsume LMT firms that for the most part acquire external, scientifically-generated knowledge as a precondition to innovation. This is also the case for LMT firms which are characterized in the literature as 'non-R&D-performers' (having no in-house R&D activities). These firms widen their knowledge base by resorting to this externally available knowledge (Rammer *et al.*, 2011; Som, 2012). This knowledge base encompasses codified knowledge that is made available in the form of models, prototypes, new materials and process technologies by research institutes, high-technology companies and public research institutions. The access of LMT firms to widely applicable knowledge sources (R&D organizations and laboratories) can only be established and retained by means of non-market, closely cooperative relations (Som, 2012, p.318). Firms achieve these by forging and sustaining network relations with external organizations to compensate for their limited internal capacities. In the literature, this is described as 'connect and develop' (Huston and Sakkab, 2006).

Local, firm-specific R&D competencies complementarily play a crucial role as they enable companies to evaluate, use and transfer external, scientifically-generated knowledge. The ability of companies to transfer global knowledge and utilize it for innovation is dependent on their skilled personnel (Som, 2012, p.318). Personnel in the food processing industry are particularly active in R&D (Menrad, 2004). The case study of a dairy company in Spain reveals its internal R&D department, which consists of only five people, to be mainly a networking group, bringing together its own laboratory and production unit with several universities and public research councils, as well as with suppliers and other innovation partners. To generate knowledge for innovation, this company organizes conferences and research projects with scientific partners (Köhler, 2008, p.12). Similar R&D-based relations can be found in highly specialized suppliers of components for the automotive industry, whose product innovations stem from use of expertise from materials science (Hirsch-Kreinsen, 2008).

The overwhelming majority of innovation of these companies is product innovation. As the literature shows, the new products tend to be high-technology components, which suggests that these firms produce ambitious, complex products (Som, 2012, p.318). However, such product innovation very often requires parallel process improvements. As case study findings from the dairy industry indicate (Köhler, 2008), this is often a matter of implementing quality assurance measures in in-house processes. This pattern of knowledge use applies to LMT firms that are not only

Table 1. Patterns of LMT firm knowledge use

FeaturePattern	Determining knowledge areas and types	Complementary knowledge bases	Forms of access to global knowledge bases	Innovation pattern	LMT firms belonging to sectors such as
Market-based knowledge use	Product- and field-specific knowledge about market situation and customer demand	Widely applicable, scientifically-generated knowledge.Local, application-oriented practical knowledge	Sales negotiations and specification of products, cooperative relations with lead-users	Product, process and service innovation (in part replicating or imitating existing technologies)	Textiles and clothing, furniture and leather-goods manufacturer, food and beverages
Supplier-based knowledge use	Widely applicable knowledge, especially suppliers as sources of machinery-embodied knowledge	Local application-oriented, practical knowledge and accumulated experience	Frequent cooperative relations with suppliers, but also purely market-based relations	Primarily process innovation technology adopters, additional specifications	Furniture and woodworking, automotive suppliers, plastic parts, mechanical and metal components manufacturing
Firm-specific knowledge pattern	Internally-available knowledge stock, mainly practical knowledge in various forms	Additional application-oriented knowledge provided by external organizations.Local firm-specific engineering and design competencies	Internal structures and routines, often trial-and-error processes	New products, continuous upgrading of existing technologies, non-technical process innovations	Fabricated metal products, furniture and woodworking, machinery and equipment
R&D-based knowledge use	Widely applicable, scientifically-generated knowledge	Local, firm-specific R&D competencies	Close non-market network relations with external scientific organizations, existence of highly skilled personnel	Ambitious, complex products, including high-tech components	Textiles, machinery, food-processing

'non-R&D-performers', but also 'contract R&D performers' (Huang *et al.*, 2010) and 'knowledge-intensive product developers' (Som, 2012, p.317). Many of the companies included here perform R&D and it can be surmised that this pattern is not unique to LMT firms but also applies to firms that are R&D intensive. The basic features of the four patterns of LMT firms' knowledge are summarized in Table 1.

Conclusion

This taxonomy of knowledge-use patterns in LMT firms highlights two factors. It emphasizes the various types and sources of knowledge relevant to LMT innovation. The taxonomy allows the classification of heterogeneous findings and displays the broad landscape of non-R&D-based, innovation-relevant knowledge. The other factor is that R&D-based knowledge, either company-internal or externally-created, must not be underestimated in LMT innovation. This holds for low R&D-performing firms as well as non-R&D-performers. The demarcation lines between LMT firms and medium–high and even high-technology sectors are blurred (Som, 2012).

What policy recommendations can be drawn? First of all, it should be pointed out that LMT research to date has made a number of valid policy recommendations. Generally, these recommendations have been targeted at increasing the awareness of policymakers of innovation in low-technology industries (Jacobson and Heanue, 2005; Arundel *et al.*, 2008; Rammer *et al.*, 2011; Som, 2012). It is not sensible to focus innovation policy solely on R&D-intensive economic sectors. LMT research has repeatedly furnished convincing evidence that, contrary to prevalent scientific and popular opinion, low-technology sectors and firms possess 'future-proof' growth and innovation potential. By incorporating LMT industries into policy measures, new growth areas may be opened up and, above all, possible development problems in research-intensive economic sectors might be avoided. Furthermore, recent research findings show that opportunities for entrepreneurship and starting new companies really exist in LMT sectors (Hirsch-Kreinsen and Schwinge, 2014). Recognition of this requires departure from the narrow understanding of innovation in which R&D intensity is the sole indicator of innovativeness.

With these general insights, more specific policy recommendations can be made on the basis of the patterns of knowledge use presented here. Innovation policy geared to LMT sectors has to deal with heterogeneous firms and innovation-relevant knowledge bases. It has to cater for differences in local, sectoral and global constellations of knowledge. Effective innovation policy needs to be informed by an integrated perspective which simultaneously takes account of firm-level variety and the divergent structural conditions of the environment (Peneder, 2010, p.334). Policy measures oriented to LMT firms have to take effect at the local level of individual enterprises, as well as at the level of their effective integration with sources of knowledge from other branches of industry and from markets (Rammer *et al.*, 2011; Som, 2012).

The local knowledge level of the individual LMT company has proved to be essential, whether it be as a complementary function or a determining factor. This knowledge represents unquestionably the specific strength of LMT firms and must be preserved. Policy aiming at this level should comprise a broad spectrum of different measures. Some policy measures should focus on enhancing the innovativeness of internal processes through practical, non-R&D, knowledge. Possible starting points are new management methods and innovation-conducive work methods. Other policy measures should focus on the development of limited in-house R&D capacities.

At the sectoral and global level, policy focus should be on the facilitation and acceleration of knowledge transfer and diffusion processes. Diffusion of globally-available knowledge to sector-specific and the firm-specific knowledge bases offers new innovation opportunities. A central precondition for this is the promotion of cooperation with research-intensive knowledge and technology suppliers. The ability of LMT firms to initiate and maintain cooperative relations has to be improved because firms, especially SMEs from mature sectors, are very often reluctant to join networks and cooperate. This is as true for firms belonging to the R&D-based pattern as for the market knowledge-based pattern. An effective approach would be the systematic use of pre-competitive joint research projects involving LMT firms, R&D-intensive organizations and lead customers. In such project groups, groundbreaking innovation could be induced and problems of transferring information overcome. Innovation policy should encourage a constant and differentiated enrichment of the innovation-relevant knowledge of LMT firms. To do this, it needs to take account of not only differences in actors, but also their complementary relations.

Disclosure statement

No potential conflict of interest was reported by the author.

Notes

1. Milestones in the field of LMT research are the EU-funded FP 5 project *Policy and Innovation in Lowtech – PILOT*, running from 2003 to 2006 (Hirsch-Kreinsen *et al.*, 2006) and the special issue of *Research Policy* on innovation in low- and medium-technology industries (Robertson *et al.*, 2009).
2. This percentage varies greatly among countries. Most eastern and southern European countries (e.g. Bulgaria and Poland) have a very high proportion of such enterprises. In many northern and western European countries (e.g. France, Netherlands, Sweden), this percentage is much lower. In Germany, around 48% of innovating companies have no in-house R&D capacities (Rammer *et al.*, 2010, p.80).
3. How to deal with multi-product and multi-technology firms which include high-tech as well as low-tech areas remains a problem. Large companies are likely to follow a variety of technological trajectories, another reason why sectoral classification can be very difficult (Archibugi, 2001).
4. This methodological approach – making new discoveries in a logical and ordered way, following neither a theoretically-grounded deductive approach nor an exclusively empirically-based inductive approach – is known as 'abduction' (Reichertz, 2009).
5. This pattern has similarities to Pavitt's sectoral pattern of technological change. What Pavitt calls 'supplier-dominated' firms are found mainly in traditional sectors of manufacturing (Pavitt, 1984, p.356).

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