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# ?Low-Tech? Research - Revisited

**Hartmut Hirsch-Kreinsen**
Dortmund University of Technology
Chair of Economic and Industrial Society
hartmut.hirsch-kreinsen@tu-dortmund.de

## Abstract

In recent years, a growing body of literature has convincingly proven the innovativeness of low- and medium-technology (LMT) firms in advanced economies. This paper reviews the main research findings and highlights the unresolved impasse in LMT research between the sectoral and the firm-led perspectives on innovation. To overcome this problem, the paper draws on the concept of technological regimes and outlines four different LMT innovation regimes. These regimes are not identical with LMT sectors but refer to different innovation patterns identified on the firm level.

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# “Low-Tech” Research - Revisited

## 1. Introduction

Recent years have seen a growing body of innovation literature devoted to the innovativeness of low- and medium-technology industries (LMT). The research interest in LMT industries is mainly motivated by criticism of the mainstream of innovation research and innovation policy, which regards a high investment in R&D and advanced technologies as the key to growth and prosperity. In contrast to this view, LMT research 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.*, 2009b). But despite the instructive character of the LMT research findings, a number of issues still remain unresolved. Foremost among these is the fact that the LMT sectors and firms are differentiated solely according to the formal criterion of R&D intensity without systematically factoring in the heterogeneous structural conditions of the respective sectors and companies. A second unresolved issue is that LMT research, just as the high-tech oriented research and policy-making assumes a linear relation between low-R&D intensity und innovations. The relevant research is for the most part based on the implicit assumption that firms which lack a specific resource, e.g. a high R&D intensity, are characterized by identical or similar innovation behaviour. This may be seen as an inversion of the linear approach of innovation which is basically criticized by LMT research (Som, 2012: pp.12).

A further essential shortcoming of LMT research is the empirical and analytical contradiction between the supposed homogeneity of LMT sectors in general and the heterogeneity of firms, a contradiction that has not yet been completely resolved. The following argument delves into this issue. As will be shown later in more detail, the mainstream of LMT studies defines individual LMT firms by their sector affiliation whereas only a few studies provide convincing empirical evidence for an inter-sectoral variation and mixture of different firm types concerning their R&D-intensities ( Tunzelmann and Acha, 2005; Kirner *et al*., 2009a).

This issue can be linked to a long-standing discussion in innovation research which centres on the tension between the micro- and the macro-levels of analysis. Peneder describes this research dilemma very succinctly: “Persistent differences between sectors draw attention towards specific technology fields, where observed regularities in industry data are interpreted as if they represent the behavior of individual firms. Conversely, the variety of firm behavior

causes many researchers to focus exclusively on micro-data. The common observation of innovative firms in LMTs, or of a considerable number of non-innovating firms in high-tech sectors, is then viewed as an antagonism, which casts doubt on the usefulness of taxonomies that characterize the competitive or technological regime of an industry" (Peneder, 2010: 323). Following Peneder and other authors ( Malerba and Orsinego, 1993, Malerba *et al.*,1997; Marsili, 2002), it will be argued below that a taxonomy of innovative firms that systematically links the macro level to the micro level of individual companies opens up an at least partial solution to this research problem. The aim of this contribution is thus to develop a classification of innovating LMT firms that encompasses the typical patterns of LMT innovation as well as their determining micro and macro factors and thereby avoids the "impasse between the meso- and micro-led perspectives on innovation" (Peneder 2010: 324). The basic assumption of this paper is that one cannot speak of a single and specific LMT innovation pattern. In fact, there are a variety of LMT innovation patterns owing to the respective technology fields, inter-sectoral variation and varying R&D-intensities in the enterprises.

The starting point for the taxonomy of this paper is the concept of technological regimes ( Winter 1984; Dosi *et al.*, 1995; Malerba and Orsinego, 1993) which describes the technological conditions and determining factors of innovative firms. From the broad debate on the concept of technological regimes (see e.g. Geels, 2004), two central characteristics will be highlighted for the following analysis: Firstly, a technological regime defines the modal properties of learning processes, the sources of knowledge and the nature of knowledge bases that are associated with the innovation processes of firms active in distinct sets of production activities (Marsili, 2002: 218). Secondly, a regime is not an industry-level construct but refers to the level of industry sub-groups or even individual firms. Therefore, firms from different types of industries and sectors may belong to the same regime (Leipoenen and Drejer, 2007: 1233).

Following this approach, typical LMT innovation regimes will be identified. The relevant knowledge bases for LMT innovation on the macro or micro level will be regarded as the key distinctive feature of different regimes; the modes of access of the individual firms to these knowledge bases and the patterns of knowledge use and innovation of LMT firms are further relevant characteristics (see section 4.1).[1] In other words, the distinguishing criterion is the

[1] The following line of argument is based on a narrow concept of a technological regime which focuses on the knowledge process in ist various dimesnions. This focus has to be distinguished frome broader understandings of this concept ( Breschi *et al.*, 2000).

question: Where does the relevant knowledge come from? As this approach is geared to knowledge and its various internal and external sources as distinguishing feature and parameter for different LMT regimes, the sectoral analysis perspective that has so far prevailed in LMT research is bypassed by the focus on different types of firms. Furthermore, the distinct focus of LMT research on the importance of different types of knowledge is taken into account. Empirically, the planned analysis is based on a re-interpretation of central findings of LMT research. Methodologically, the taxonomy of LMT innovation regimes has to be regarded as hypotheses that need further validation and set the direction for future research.

The paper includes the following steps: In a first step the main research findings on innovation in LMT industries and their dynamics and prospects will be summarized. In a second step, the unresolved question of the empirical and analytical contradiction between the supposed homogeneity of LMT sectors and the heterogeneity of individual firms will be discussed in detail. In a third step a taxonomy of LMT innovation regimes will be outlined and the various LMT regimes will be compared with Pavitt's generally oriented taxonomy of divergent innovation patterns. It will be shown that there are often only gradual distinctions between the innovation behaviour of companies with different R&D-intensity. In a last step, it will be examined whether new recommendations on innovation policy can be inferred from these considerations that go beyond the current state of the art.

## 2. Main findings of LMT research

A key focus of LMT research has been to assess the ability of LMT companies and industries to innovate. In fact, researchers have questioned whether LMT companies are innovative at all. They have also investigated which specific courses of innovation activities they take and which conditions and determinants are relevant to them. The mainstream of LMT research conducted during the last ten to twelve years followed a sectoral perspective guided by the R&D intensity indicator; based on the OECD classification (OECD, 2005) it focused on industrial sectors with a R&D intensity below 3%, defined as LMT. This mainstream research can be differentiated as follows: [2]

Many studies have dealt with the technological development of firms from selected LMT sectors such as the forest industry ( Palmberg, 2001; Chamberlin and Doutriaux, 2010), food

[2] Milestones in the field of LMT research were the EU funded FP 5 project "Policy and Innovation in Lowtech – PILOT" running from 2003 – 2006 (Hirsch-Kreinsen *et al.*, 2006) and the Special Issue of Research Policy on Innovation in Low-and Medium-Technology Industries (Robertson et al., 2009a).

processing ( Menrad, 2004; Rama, 2008; Manniche and Testa, 2010), mechanical engineering ( Schmierl, 2005; Freddi, 2008; 2009; Chen, 2009) and packaging and paper ( Hansen and Serin, 1997; Ghosal and Nair-Reichert, 2009).

A majority of LMT studies have focused on firms from the complete range of LMT industries from across the whole of the EU ( Bender *et al.*, 2005; Tunzelmann and Acha, 2005; Arundel *et al.*, 2008; Hirsch-Kreinsen, 2008¸ Sáenz *et al.*, 2009; Huang *et al.*, 2010). Others have concentrated on LMT firms and sectors from individual countries such as Spain, the UK, Denmark or Germany (e.g. Rotaba and Beaudry 2009; Santamaria *et al.*, 2009; Hansen, 2010; Hervas-Oliver and Albers, 2011; Som, 2012) or have considered regional LMT agglomerations ( Maskell, 1998; Jacobson *et al.*, 2001; Teixeira *et al.*, 2008; Christensen, 2010; Jacobson and Garibaldo, 2011).

In terms of methodology, the vast majority of LMT studies are of a quantitative nature and are based on large data sets, such as the Community Innovation Survey (CIS) and the German Manufacturing Survey (GMS) ( Arundel *et al.*, 2008; Heidenreich, 2009; Kirner *et al.*, 2009a; Rammer *et al.*, 2010; Som, 2012). These statistical analyses have also often been used to systematically identify and compare the specific characteristics of innovation in LMT and high-and-medium-high technology (HMT) sectors ( Heidenreich, 2009; Rammer *et al.*, 2010; Rotaba and Beaudry, 2009; Som, 2012). A smaller group of studies is based on case study analyses ( Maskell, 1998; Palmberg, 2001; Bender *et al.*, 2005; Hirsch-Kreinsen *et al.*, 2006; Hansen and Winther, 2011).

All in all, this research has clearly demonstrated that LMT industries should be regarded as innovative: 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). But it has also become evident that LMT firms are less innovative than high and medium-high technology (HMT) firms. The European Community Innovation Survey (CIS) shows that whereas only 37% of LMT firms were judged to be innovative between 2002 and 2004, the figure for HMT firms amounted to more than 55% (Heidenreich, 2009: 486). These general findings can be elaborated on as follows.

### 2.1 Dominance of process innovations

Virtually all research concurs in the particular importance of process innovations ( Evangelista and Mastrostefano, 2006; Heidenreich, 2009; Kirner *et al.*, 2009b; Huang *et al.*, 2010; Rammer, 2010). According to analyses of CIS data for 2004, it is twice as important for innovating LMT companies (36%) as for innovating HMT companies (17%) (Heidenreich,

2009: 486). Recent data from the German Manufacturing Survey (GMS) for 2002 to 2008 largely corroborates these findings by pointing to the much greater importance of technical process innovations for innovative non-researching firms than for research-intensive companies (Rammer *et al.*, 2010: 132). Yet only a small minority of these LMT firms can be characterised as pure technology adopters that take on ready-to-use new process technologies. The large majority conducts 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: Organizational innovations such as the introduction of new forms of company organization or new sales and logistic concepts are often directly linked to technical innovation processes. According to the available data, this type of non-technical innovation is as important as technical-based process innovation activities in LMT firms and in this regard LMT firms do not differ significantly from HMT firms (see below, Heidenreich, 2009; Rammer *et al.*, 2010; Som, 2012).

Two factors are cited for the importance of process innovations for LMT enterprises. Firstly, process innovations can to a large extent be carried out relatively smoothly even without own R&D competencies, as their 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 new technology into existing processes, reorganization measures and the retraining of employees (Rammer *et al.*, 2010: 84). These adaptation activities usually take place within the context of ongoing operations and under the direction of production management, i.e. on the shop floor. Additional investments into in-house R&D activities are therefore normally not required. Secondly, 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, to improve their efficiency and so to assure their competitiveness ( Cox *et al.*, 2002; Heidenreich, 2009; Kirner *et al.*, 2009a).

By comparison, a similarly important role is ascribed to product innovation (Rammer *et al.*, 2010). However, product innovation play a far greater role for HMT industries than for LMT industries. According to CIS-data, 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: 486; similar: Arundel *et al.*, 2008). Data for Germany reveals a similar ratio (Rammer *et al.*, 2010: 132). So far, research has offered few explanations for this. One can surmise though that product innovation demand the use of new technologies to a far greater extent than process innovations ( Huang *et al.*, 2010), calling for technology-oriented competencies and possibly specialized R&D capacities which LMT firms often do not have or if so, only on

a small scale. Various research findings substantiate this interpretation (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 in order to accommodate changing customer demands. On the other hand, product innovations can also include a redesign as well as a functional and technological upgrading. These measures are often closely connected to the already mentioned organizational and market-oriented process innovation. With these innovation, the non-research-intensive companies aim to react quickly to changing customer preferences and attempt to create new sales segments by particular branding measures, such as the introduction of trademarks for LMT products and additional service activities. Thus researchers emphasize the fact that many LMT companies regard service innovations as an increasingly important innovation potential (Kirner *et al.,* 2008; Improve, 2011; Mamede and Fernandes, 2012).

**2.2 Multiple knowledge sources**

The availability of knowledge and access to sources of information pertinent to innovation constitute key dimensions of LMT research. All in all, the findings refer to multiple knowledge sources for LMT innovation. It has been shown that the in-house knowledge and information bases are crucial sources for the success of LMT innovation processes. According to CIS-data, 40.6 % of all innovating LMT firms stated that their in-house sources of information were highly important for innovation. However, for HMT firms the importance of in-house information sources is markedly higher (55% of innovating firms). This is evidently due to the in-house R&D capacities at their disposal (Heidenreich, 2009: 488). These research findings are corroborated by analyses of other data for the EU-15 (Arundel *et al.*, 2008; Huang *et al.,* 2010) and for Germany (Rammer *et al.*, 2010). Given their lack of R&D capabilities, formalized processes of knowledge generation play an insignificant role for LMT firms. Instead, innovation activities proceed in the form of “practical and pragmatic ways of doing and using” (Tunzelmann and Acha, 2005: 417), meaning that the knowledge which is relevant for these enterprises can be regarded as application-oriented practical knowledge ( Maskell, 1998; Arundel *et al.*, 2008; Hirsch-Kreinsen, 2008). This term stands for a complex bundle of different knowledge elements made up of explicit, codified and formalised elements such as design drawing and requirement specifications for new products and, more significantly, implicit elements such as accumulated experience and well-established, proven and tested routines for solving technical problems. An example of this is process innovation activity ( Rammer *et al.*, 2010). On the one hand, enterprises make use of

engineering knowledge that is 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 about, for instance, the shortcomings of production technologies currently in use and about innovation needs ( Ghosal and Nair-Reichert, 2009).

Furthermore, research has revealed that external knowledge bases play a larger role for LMT innovation than in-house knowledge bases. 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; Hauknes and Knell, 2009). In a conceptual perspective, the literature refers to these external knowledge sources as "distributed knowledge base" (Robertson and Smith, 2008). This knowledge base is made up of different forms of knowledge stemming from various, independent players, who come from different sectors and technology fields. Empirical findings suggest that this knowledge base is the main source of knowledge generation for LMT companies ( Robertson and Patel, 2007). It is therefore not surprising that market and sales information sourced from customers and competitors are very important drivers of LMT innovation ( Grimpe and Sofka, 2009; Heidenreich, 2009; Rammer *et al.*, 2010). Basing his findings on the CIS-data for 20 EU Member States, Heidenreich shows that more than 35% of all innovating LMT firms regard these information sources as highly important (Heidenreich, 2009: 489). Moreover, more detailed research shows that customer input is particularly significant for product innovation. According to the CIS-data, this source of information is of particular importance for around 24% of innovating LMT firms (Heidenreich, 2009: 489).

Because of the relevance of process innovation, the knowledge provided by suppliers also plays a larger role in LMT than HMT innovation ( Cox *et al.*, 2002; Heidenreich, 2009; Rotaba and Beaudry, 2009; Rammer *et al.*, 2010). About 25% of all LMT firms refer to this source of information as extremely important (Heidenreich, 2009: 489). This type of knowledge usually concerns machines and other technological components and is envisaged as 'embodied knowledge' ( Arundel *et al.*, 2008). In contrast, scientifically generated and codified knowledge is less important for LMT innovations. 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 have indicated that HMT firms make much more intensive use of such sources than LMT firms as catalysts for innovation ( Grimpe and Sofka, 2009; Kirner *et al.*, 2009b). According to Heidenreich's analysis of the CIS-data, 6.2 % of all HMT firms as opposed to only 3.2% of

all LMT firms refer to the scientific domain as an important source of information (Heidenreich, 2009: 489).

### 3. The unsolved micro-macro issue in LMT research

In most of the aforementioned studies, the authors focused on LMT firms from LMT sectors. In other words, they equated LMT firms with LMT sectors, assuming the uniformity of LMT industries and sectors. Therefore, their more or less explicit basic assumption was that conclusions can be drawn from the level of an entire sector to the level of individual firms. In the words of Paul Robertson, they fell "…into the trap of equating low-technology industries or sectors with low-technology firms." (Robertson *et al.,* 2009a: 442). So far, only few LMT studies have explicitly broached this issue. These studies (which may be called non-mainstream studies) broaden the perspective of LMT research by introducing a more general and comprehensive understanding of industrial innovativeness ( Tunzelmann and Acha, 2005; Kirner *et al.,* 2009a; Huang *et al.,* 2010; Som, 2012): On the one hand, they second the LMT mainstream position that high R&D intensity cannot simply be equated with high innovativeness. On the other hand, they look critically at another mainstream position of LMT research. They show that the high-, medium-, and low-tech sectors comprise a considerable mix of high-, medium-, and low-tech firms. Thus, for instance, data on the food industry in Germany shows that despite its overall low R&D intensity, there are significant differences between individual companies in this regard (Menrad, 2002). These findings convincingly suggest that general statements about clearly definable sectors in terms of the link between R&D intensity and innovativeness may be compromised by intra-sectoral heterogeneity (Kirner *et al.,* 2009a: 447). [3]

Therefore, some studies hence opt for an analysis of the micro level of individual companies to be able to identify differences and similarities in the innovation behavior of LMT companies regardless of their sectoral affiliation. On the basis of case study analyses, Hirsch-Kreinsen (2008) and Köhler (2008) distinguish between several, relatively similar types of LMT innovation strategies. Thus Hirsch-Kreinsen identifies three different innovation strategies that are termed "step-by-step product development", "customer-oriented strategy", and "process specialisation" (Hirsch-Kreinsen, 2008). Similarly, Huang et al. too refer to three different LMT innovation types. On the basis of an analysis of CIS data, they

[3] The question remains open how to deal with multi-product and multi-technology firms which include high-tech as well as low-tech areas. Large companies like IBM, GM, and Toshiba are likely to follow a variety of technological trajectories. That is another reason why a sectoral classification very difficult ( Arcishibugi, 2001).

differentiate between ”technology adopters“ that acquire new technologies from outside, “non-R&D innovators” that conduct non-R&D-based innovative activities in-house, and “contract R&D performers” that contract external R&D activities (Huang *et al.*, 2010). The methodologically most sophisticated study is doubtlessly the study by Som, which distinguishes between five LMT innovation patterns on the basis of a cluster analysis of GMS data on the German industry (Som, 2012: pp. 317): viz. “knowledge-intensive product developers“, ”customer driven, technical process specialists, “occasional B2B product developers“, “low-innovative, labour-intensive manufacturers“, and “volume-flexible, specialised suppliers“.

All in all, these empirical innovation types share many similarities.[4] They all prove that LMT firms defy a simple sector-based classification because they are very different at the micro level in terms of e.g. their particular technology base and their industry classification, their size, organisational structures and in-house capabilities as well as their position in the value added chain. In other words, specific sectoral structural conditions and particular in-house innovation strategies cannot be directly linked to each other. Theoretically, this heterogeneity of the companies can, firstly, be accounted for by taking recourse to the evolutionary assumptions of innovation research ( Nelson and Winter 1982; Nelson 1991). These convincingly show that the divergence of company strategies can be attributed to different structural conditions of the individual companies and the hence resulting different modes of strategic choices (Som, 2012: 116). This heterogeneity can, secondly , also be accounted for by referring to the well-known approach of dynamic capabilities from innovation and management research. A key message of this widely discussed concept is that the firm-specific resource and competence structures have a significant influence on the diverging innovation strategies ( Bender and Laestadius, 2005).

At the same time, however, this typification does not resolve the problem of the embedment of the individual firms in their structural conditions, i.e. the macro level. For the conditions of different industrial sectors and their influence on the innovation behaviour of companies may by no means be left out of the analysis. Conceptionally, this issue is focused on by the research on the systemic character of innovations and the influence of structural socio-institutional factors on the innovation behaviour of individual firms ( Edquist 1997). Empirically, LMT studies that emphasise the extremely important influence determinants

[4] Furthermore, these types converge with conceptual considerations by Arundel et al. who outline various LMT innovation methods as „technology adoption“, „minor modifications“, „imitation including reverse engineering“, and „combining existing knowledge in new ways“ (Arundel *et al.*, 2008).

such as demand and the market have on innovations point to the importance of this nexus ( Tunzelmann und Acha, 2005). Innovation courses can only be explained and recommendations for innovation policy be sufficiently justified once the interaction of macro and micro conditions is considered (Peneder, 2010).

## 4. LMT innovation regimes

### 4.1 The basic features

Suggestions for resolving this conceptual issue can be found in the concept of technological regimes introduced above. As explained, with the aid of this category the various distinguishable innovation patterns will be traced back to the specific forms of using different sources of knowledge of the micro and macro levels. Thus the innovation behaviour of individual companies will be systematically linked to the macro conditions. To do so, it is helpful to revert to categories from Science&Technology Studies, that differentiate between global and local dimensions of knowledge ( Rip 1997). These argue that local knowledge refers to, and is embedded in, a certain local situation whereas global knowledge is in principle generally available. These two types of knowledge differ with regard to their validity claims – universality in the one case vs. adequacy in the other. And they differ in form as well. Global knowledge is always codified as it refers to a paradigm whereas local knowledge, though having codified elements (instruction handbooks, formal organisational rules, technical process protocol etc.), is characterized by some degree of tacitness (Bender and Laestadius, 2005: p. 136). With these categories, one can differentiate between generally available knowledge at the macro level and company-specific knowledge at the micro level and one can investigate which sources of knowledge are of particular importance for particular innovation processes. The central characteristics of a LMT innovation regime can thus be stated more precisely (see section 1): Firstly, the knowledge source that dominates in each case; secondly, the forms of access of the individual firms to the different global knowledge sources; thirdly, the local firm-specific knowledge base as the relevant prerequisite to transfer globally available knowledge into the firm and the prevailing innovation type. The available knowledge sources generally point to innovation opportunities of which the companies make use. These sources can e.g. be knowledge about global market und technological opportunities or local in-house knowledge bases.

On this basis, different LMT innovation regimes will be identified below. Methodically, they are based on a reinterpretation of the findings of the above-mentioned studies that identified various LMT innovation types at the micro level of the companies ( section 3). While these

types, as already mentioned, do not systematically take account of the macro level of innovations, they nonetheless point to global sources of knowledge such as market expertise or knowledge about new technologies. On this basis, typical LMT innovation regimes can be defined in a first approximation. It goes without saying that from a methodological point of view, this is only a first approximation to a classification, which is consequently of a hypothetical nature. Further systematic empirical analyses are still needed to specify and validate it.

### 4.2 Characteristics of LMT innovation regimes

In the following, four LMT innovation regimes will be distinguished: The first type of LMT regime can be termed *market-driven*. It is characterized by a strong customer- and market-orientation of the innovating firms. The globally available knowledge about the market situation is the determining factor for the innovation activities of the firms. As the findings show, it is occasionally supplemented by the selective use of knowledge from external R&D organizations. This is new knowledge on promising product designs and new marketing strategies or also engineering expertise and experience concerning the design of new processes and equipment. In general, this is globally available knowledge. Thus the knowledge on market structures and customer preferences is normally generally available to all companies in the form of studies, general marketing knowledge or also fair presentations. The same is true for the relevant technological or marketing knowledge that is generally readily available as codified knowledge.

The innovation activities of these companies include product, process and service innovation. Usually, the firms develop their products incrementally according to customer demands or specifications. Likewise, the process and service innovations are geared to the given sales situations with the aim of improving the flexibility and delivery capacity of the companies and, secondly, of boosting the customer relations by means of additional service offers. These market-driven innovation activities can include the pure replication or imitation of products and processes that are already available ( Arundel *et al.*, 2008).

The companies access these global knowledge sources in various ways: Firstly, organized sales negotiations with customers, in which the specifications of products are decided on, play an important role. Secondly, the research findings show that long-lasting and cooperative relations to lead-users and to lead-producers within the framework of supply chains are also of particular importance. An example for 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 specific cholesterol-reducing dairy product (Köhler, 2008: 14). In this case - as is generally true- the successful use of global knowledge by the LMT firms depends on the local knowledge and the therewith connected transfer abilities of the companies. As aforementioned, this local knowledge base is shaped especially by application-oriented practical knowledge, whose importance can in particular be attributed to the lacking in-house R&D capacities and the lack of systematic structures for innovation processes. In addition, the companies with these regimes have an altogether lower skill level.

Examples of this innovation regime are company activities of textile and clothing industries as well as of furniture and leather goods manufacturers, whose product development is geared to anticipatable fashion cycles and whose existing product lines call for more or less continuous variation. Other examples can be found in the food and beverage industry with their prevailing small and medium-sized enterprises highly flexibly produce for specific market segments. Focused on the micro-level of individual firms, this innovation regime includes firms strategies termed “customer-oriented strategy” (Hirsch-Kreinsen, 2008) or “customer-driven, technical process” and “volume-flexible, specialised suppliers“ (Som, 2012). On the whole, the statistics of the GMS indicate that this type of LMT innovation regime is prevalent across many industrial sectors. The firms considered here can thus also be characterized as typical ”non-R&D innovators“ (Huang *et al*., 2010).

Following Pavitt’s (1984) taxonomy, the second type of LMT regime can be termed *supplier dominated*. It is characterized by the great significance of external suppliers as main knowledge sources for the innovation activities of the respective firms. This knowledge base is of an explicitly global character and is available as knowledge embodied in machinery as well as in codified form in terms of formal organization rules, instruction handbooks, management concepts, check lists etc. In conjunction with these external knowledge sources, the local knowledge base of the firms plays an important but subordinate role, as the firms merely act as “technology adopters“ (Huang *et al.*, 2010) or adapt the global knowledge to their respective company conditions by means of additional specifications. As mentioned before, the adoption of new machinery requires efforts on the part of the innovating LMT firm such as the integration of new technology into existing processes and the reorganization or the retraining of employees (Rammer *et al.*, 2010). These adaptation activities usually take place within the context of ongoing operations on the shop-floor. In other words, on the local firm level application-oriented practical knowledge and accumulated experiences about the

bottlenecks and needs of the manufacturing processes are of major significance for the implementation of new process technologies.

The innovation activities advanced on this basis are thus 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 quasi as a by-product. The main objective of the process innovation is, however, the continuous improvement in the companies' efficiency in order to increase their competitiveness ( section 2.1).

There is only little evidence in research on the prevailing mode of access of LMT firms to the global body of knowledge. Solely general data points to the fact that cooperative relations with suppliers can be seen as crucial for innovation activities (Heidenreich, 2009; Rammer *et al.*, 2010): However, it must be surmised that cooperations with suppliers are only of importance to those LMT firms which require specifications and adaptations of the globally available technologies.

As the research findings show, the respective enterprises belong to industrial subsectors which mainly manufacture their products at a relatively high level of automation and with the aid of integrated process technologies. Firms from the furniture industry are an instructive example of this. They are extensively automated on the basis of a significantly reduced variety of parts and of simplified processes. A second example is the continuous further development of processes in woodworking firms, which experts believe have achieved an extremely high level of process performance and process precision hardly comparable to other industrial sectors. Similar trends can also be discerned in sheet forming companies and firms manufacturing plastic parts, mechanic components or aluminium parts. Paper manufacturing and the intricate processes in the food processing industry are other examples of this innovation regime. Its technologically highly sophisticated processes are continually optimized and developed further. Apart from processes with a high technological level and automation degree, the innovation activities of this regime also comprise processes with relatively simple, standard techniques which are continually "cultivated". LMT research terms the firms belonging to this innovation regime "process specialists" (Hirsch-Kreinsen, 2008) or "volume-flexible specialised suppliers" (Som, 2008). According to research, these innovation strategies are very widely used ( Arundel et al., 2008).

The third type of LMT innovation regime can be referred to as *engineering-driven*. It is characterized by the high relevance of global knowledge sources such as engineering-oriented research institutes and other specialized research organizations which provide technological application-oriented knowledge. However, in conjunction with these external sources of knowledge, local firm-specific R&D and design competencies too play an important role as knowledge sources for innovation activities. The implemented innovation activities mainly relate to relatively complex products. According to the empirical findings, these product innovation are often complemented by innovative organizational and management concepts.

As the available data shows (Som, 2012: 318), the access of LMT firms to the global knowledge sources is in particular facilitated and secured by close cooperation relations. In the literature, this procedure of LMT firms is depicted as "connect and develop" (Huston and Sakkab, 2006). The ability of companies to transfer the global knowledge and to utilize it for innovation activities is to a great extent based on their relatively high share of highly skilled personnel. In that, the companies described here by all means possess a certain R&D intensity, that actually have to be classified as "medium-low-tech" as measured by the average of the industry as a whole.

As the statistical data from the GMS show, this innovation regime too comprises LMT firms from sectors of various R&D intensities and has a relatively high share of all LMT enterprises in the German industry (ibid.). As the results of case study research show (Hirsch-Kreinsen, 2008), many of these firms belong to the industrial subsectors of "fabricated metal products", "wood products & furniture" and "machinery and equipment". These firms are often suppliers of the automotive industry which do not only produce minor parts but also rather complex components. All in all, this LMT regime is characterized by multiple knowledge sources and a highly developed complementarity of global and local knowledge bases whose interaction constitutes a complex knowledge level. Hence, the firms belonging to this regime are also referred to as "knowledge-intensive product developers" in research (Som, 2012). Following Arundel et al., this kind of innovation behaviour can also be described as "combining existing knowledge in new ways" (Arundel *et al.*, 2008). It can, however, be surmised that this pattern is not unique to LMT firms but also applies to firms with a markedly higher R&D intensity. The boundaries to medium-high-companies, for instance from the mechanical engineering sector, are blurred here.

A fourth type of LMT regime can be termed *R&D-driven*. This characterization might be regarded as a contradiction in terms. However, this category is used to subsume LMT firms

that for the most part specifically acquire external, scientifically generated knowledge to utilize it for their innovation strategies. This knowledge base is of a global character and encompasses codified knowledge that is made available in the form of models, prototypes, new materials and process technologies by research institutes, high-tech companies and public research institutions. In connection with these external knowledge sources, the existing local firm-specific R&D competencies too play a major role, as they enable the companies to evaluate, use and transfer the external, scientifically generated knowledge.

The overwhelming majority of innovation activities of these companies are product innovation. As mass data show, the new products consist of high-tech components in an above-average share of firms, which suggest that these firms mainly produce ambitious, complex products (Som, 2012: 318). This innovation pattern can be found in LMT firms from all industries, but particularly so in LMT firms from the chemical industry, electrical machinery, textiles and machinery, that all cooperate very closely with R&D organisations (Kirner *et al.*, 2009b: 65). Furthermore, LMT firms from the food processing industry that develop highly science-based products must also be mentioned. As is shown by data on the German food industry, scientifically created knowledge and techniques are gaining increasing relevance for new products (Menrad, 2002: 867). Thus Tunzelmann and Acha show e.g. that the seemingly simple packaging of readymade and microwavable foods for sale in supermarkets requires very sophisticated analyses of smart materials in order to combine heat responsiveness, gas release, ease of production, ease in filling during processing and ease of consumer use (Tunzelmann and Acha, 2005: 427). However, such product innovation very often require parallel process innovation. As case study findings from the dairy industry indicate (Köhler, 2008), it is often a case of implementing measures of quality assurance in the in-house process as well as of assuring the quality of the pre-products.

In addition, it can be asserted that the access of LMT firms to the global knowledge sources, i.e. to R&D organizations and laboratories, can generally only be established and retained by means of close cooperation relations. The firms achieve these by forging and sustaining network relations with external organizations in order to compensate for their ultimately limited internal capacities. Thus the case study findings on a dairy company in Spain for instance show that its internal R&D department, which consists of only five people, is 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 new innovation, this company organizes conferences with scientists and carries out research projects together with scientific partners (ibid.: 12).

Similar R&D-based cooperation relations can, for instance, be found in the case of highly specialized suppliers of components for the automotive industry, whose product innovations are due to the continuous use of expertise of the materials sciences.

In general, it can be observed that the use of global scientifically generated knowledge by LMT firms, similar to the engineering-driven regimes, greatly depends on the firms having a relatively high share of highly skilled personnel (Som, 2012: 318). As research findings from the food processing industry show ( Menrad *et al.*, 2004), its personnel is particularly active in R&D, so that these companies, as measured by the average of the whole industry, can be classified as medium-low-tech rather than as low-tech. It must, however, be emphasized that these are by no means predominantly large enterprises which generally have a science- based innovation regime ( Pavitt, 1984; Marseli, 2002). In fact, most of these are small and medium-sized enterprises, which again make up the majority of LMT enterprises at large ( Kirner *et al.*, 2009b). This innovation regime categorizes LMT firms that are also conceived as "contract R&D performers" (Huang *et al.*, 2010).

### 4.3 Comparative perspective

Although the above research findings still require systematic validation, the following conclusions seem plausible regarding content and methodology: Firstly, there is no single dominant LMT innovation regime. Secondly, there is a variety of LMT innovation regimes, depending on the companies' specific technology fields, inter- and intra-sectoral variation and the differences in actual R&D intensities. Finally, the question arises to which extent the innovation behaviour of LMT firms differs from that of HMT firms? The general findings of LMT research summarized in section 2 give a first answer. They show that there are often only gradual differences between the companies from different R&D intensity sectors with regard to their focal points, the relevant knowledge sources and their cooperation behavior.

This interpretation can be specified by means of a very first and tentative comparison of LMT innovation regimes with general categories of innovation patterns that have been known for a long time in innovation research. For this purpose, the prominent taxonomy by Pavitt (1984), who differentiates between supplier-dominated, production-intensive, and science-based innovation patterns has to be considered. If one - despite their conceptual fuzziness - compares these categories with the aforementioned LMT regimes, the following can tentatively be argued: There is undoubtedly a high level of identity in the cases of the supplier-dominated patterns and the supplier-driven LMT regimes. Both are characterized by the high relevance of external suppliers as main knowledge sources for the innovation

activities of the firms. Thus Pavitt´s remark that supplier-dominated firms can be found mainly in traditional sectors of manufacturing proves to be true (ibid.: 356). Between Pavitt´s other two innovation patterns and the LMT regimes, partial overlappings can be detected. This applies, firstly, to Pavitt's science-based pattern, that encompasses companies with distinct in-house and out-house R&D activities. If one differentiates this perspective, the science-based LMT regime with its specific feature of low in-house R&D capacities can for all intents and purposes be placed in this category – for instance in terms of a subsystem. Secondly, this is also true for Pavitt's innovation pattern of production-intensive firms, which most notably includes large-scale producers with highly developed in-house engineering and technical capacities. In its basic features - a strong process orientation and the combination of global and limited local engineering-oriented knowledge sources - the outlined engineering-driven LMT regime does not greatly deviate from Pavitt's category and can be placed within this general field. Only the market-driven LMT regime is difficult to integrate in this comparison. On the one hand, it can be regarded as an element of production-intensive patterns, insofar as the innovation focus is on processes. On the other hand, this regime can also be considered a LMT peculiarity as it is closely coupled with the specific and difficult market conditions of low-tech companies.

All in all, there are obviously no fundamental divergencies between low-tech and high-tech innovation regimes. Differences are rather a matter of degree. However, further research is needed to validate these arguments.

## 5. Conclusion

Which policy recommendations can be drawn from the outlined considerations? First of all, it must be pointed out that the research to date has made a number of valid policy recommendations. Generally, these recommendations are targeted at increasing the awareness of policy-makers with respect to low-tech industries. They emphasise that it is not justified to focus innovation policy solely on economic sectors with a high R&D intensity. LMT research has repeatedly furnished convincing evidence that contrary to the prevalent scientific and popular opinion, low-tech sectors and firms do possess future-proof growth and innovation potentials. By incorporating LMT industries in policy measures, new growth areas could be opened up and, above all, possible development problems of research-intensive economic sectors could be compensated. An essential precondition for this is the departure from the too narrow focus on R&D intensity as sole indicator of innovativeness and from the

accompanying bounded understanding of innovation (see e.g. Jacobson and Heanue, 2005; Arundel *et al.*, 2008 ).

Building on these insights, more specific policy recommendations can be made on the basis of the here presented taxonomy of LMT innovation regimes. As the findings show, innovation policy geared to LMT sectors has to deal with heterogeneous firms and innovation strategies. It has to cater to the typical differences with respect to their local-global constellations of relevant knowledge sources. Effective innovation policy needs to be informed by an integrated perspective which simultaneously takes account of firm-level variety and structural conditions of their environment ( Peneder, 2010: 334). Therefore, LMT-oriented innovation policy measures have to take effect at both the local level of individual enterprises as well as at the level of their integration with global sources of knowledge from other branches of industry and in particular also from markets (see e.g. Rammer *et al.*, 2010; Som, 2012):

- At the local level of LMT firms, the focus should be on the promotion and further development of the specific competencies and skills that enable the companies to identify important external knowledge, to merge it with the existing in-house knowledge and to capitalize on this new knowledge for innovation. This can be achieved by enhancing the competence level in the predominantly small and medium-sized enterprises, by introducing new management methods and innovation-conducive work methods as well as by introducing limited in-house R&D capacities.
- At the level of integration with the global knowledge sources, the focus should be on the facilitation and acceleration of transfer and diffusion processes of the global knowledge that represents new knowledge to the individual LMT firms. A central precondition for this is the promotion of cooperation relations of all kinds both with the side of research-intensive knowledge and technology suppliers and with the increasingly important demand side. An effective approach for this purpose would be the systematic use of the instrument of pre-competitive joint research projects including LMT firms, R&D intensive organizations and/or lead-customers. In such project groups, ground-breaking innovation could be set about and at the same time transfer and communication problems between actors of different levels of action and knowledge intensity could be solved.

In other words, innovation policy should be geared to promoting a constant enhancement of the innovation ability of LMT enterprises. In doing so, the strongly diverging but also complementary relations between the different local and global knowledge levels have to be considered.

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