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''Low-Tech'' Innovations

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ABSTRACT This paper is about an industrial sector which, according to the usual socio-scientific indicators, is referred to as ''low-tech'', respectively as non-research intensive and which mostly comprises ''traditional'' industries. The interest in this sector is motivated by the contradictory situation that, on the one hand, the debate about the perspectives of modern societies focuses on the rapidly growing importance of technological innovations, knowledge and research-intensive economic sectors while, on the other hand, traditional industries make up a considerable fraction of employment and production, especially also in developed economies. On the basis of the results of extensive empirical research, this contribution tries to find answers to the basic question, whether one can speak of an innovation mode typical of the low-tech sector. The institutional based innovation systems approach forms the categorical basis of the analysis. In order to elucidate the specific features of low-tech innovations, they are, in conclusion, compared to the general characteristics of high-tech-based innovation processes.

KEY WORDS: Low-technology, industrial innovations, innovation system, industrial development

1. Introduction

In innovation research, the term ''low-technology'' denotes those industrial sectors that have no or low R&D expenditures. The basis of this categorization is the R&D intensity indicator which measures the ratio of the R&D expenditure to the turnover of a company or to the output value of a sector. By means of this indicator, sectors with a R&D intensity of more than 5 per cent are characterized as ''high-tech'' or ''high-technology'' and those with a R&D intensity of between 3 and 5 per cent as ''medium-high-tech'' or ''complex technologies''.[1] Sectors with a R&D intensity of between 3 and 0.9 per cent are classified as ''medium-low-tech'' and those with a R&D intensity below 0.9 per cent as ''low-tech''. The latter two are in the following subsumed under ''low- and medium-technology'' (LMT), respectively under ''non-research intensive''. As regards the industrial sector, mostly traditional industries such

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[1] This indicator covers in-house R&D expenditures for R&D staff, further R&D costs and investments as well as out-house expenditures, for example, for R&D tasks assigned to other companies and organizations (OECD, 2002: 108).

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as the manufacture of household appliances, the food industry, the paper, publishing and print industry, the wood and furniture industry and the manufacture of metal products—such as the foundry industry—as well as the manufacture of plastic products are regarded as low-medium-tech. In contrast, pharmaceuticals, the electronic industry, medical engineering and vehicle construction, the aerospace construction industry as well as large parts of mechanical engineering as well as the electrical industry are categorized as high-tech and medium-high-tech (cf. OECD, 2005).

The interest in LMT industries is motivated by contradictory aspects: on the one hand, the socio-scientific and the public debate about the perspectives of modern societies is characterized by the perception that only the massive increase of R&D institutions and of innovations based on high-tech will in the long run safeguard jobs and wealth, given the growing global competition. The growing importance of knowledge work, knowledge management and knowledge-based organizations in the context of deeply changing social and economic societal structures is emphasized in unison. On the other hand, however, the surprising viability of the non-research-intensive industrial sector in the developed economies of the Western countries to this day cannot be ignored. In relation to the manufacturing industry as a whole, the industrial LMT of a large number of industrialized OECD countries has a high employment share of more than 60 per cent.[2] A further indication of the importance of this sector is empirical evidence which underlines the innovation ability of many of the enterprises that are classified as LMT with regard, for instance, to continuous product development (e.g. Laestadius, 1995; Maskell, 1998; Schmierl, 2000; Palmberg, 2001).

Last but not least, the LMT sector has on various occasions been the subject of the innovation debate in the past few years and it was asked whether this sector can be sufficiently distinguished from others, thus allowing researchers to determine its significance for the technological and socio-economic development more exactly (e.g. Schmierl, 2000; Cox *et al*., 2002; Godin, 2004; Mendonça and Tunzelmann, 2004; Hirsch-Kreinsen *et al*., 2005; Smith, 2005; Tunzelmann and Acha, 2005). This debate reveals two things: for one thing, the R&D intensity indicator is not very helpful for a closer analysis of the technological specifics of the enterprises and industrial sectors in question due to its unidimensionality, as the complexity of innovation processes is thus reduced to the input of measurable figures. In other words, for understanding innovation processes it is necessary to look at innovations directly, not through R&D expenditures, but for instance through survey questions and case studies (Cox *et al*., 2002: 269). For another thing, as recently pointed out by Tunzelmann and Acha (2005), it is hardly feasible to classify the LMT sector according to criteria such as product similarity or a common technological basis due to the diversity of its subsectors. The well-known taxonomy by Pavitt (1984) classifies industrial sectors into three main categories according to their technological characteristics: ''supplier dominated'', ''production intensive'' and ''science based''. As will be shown later in more detail, this taxonomy, particularly the category of ''supplier dominated'' industries, refers to an important aspect of LMT industries and their innovation mode: technical change mainly comes from the suppliers of equipment and examples for this are traditional sectors of

[2] Shares of employment in total manufacturing, 1980–99 in 11 OECD countries including Austria, Denmark, Finland, France, Italy, Japan, Norway, Portugal, Spain, Sweden and USA (cf. Kaloudis *et al*., 2005). For shares of LMT employment in total employment in the EU in 1995 and 2006 see Heidenreich (2008).

manufacturing like textiles and house building (ibid.: 356). However, given the diversity of LMT, there might be further important features, for example, specific internal organizational and managerial capabilities, that are important for innovation too. Again following Tunzelmann and Acha (2005: 414), characteristics of innovation processes typical of low-tech can be determined when asking for the "key drivers" of LMT innovations. Based on a classification by Sutton (1991, 1998), they identify turbulent demand structures and new technological developments in the field of general purpose technologies as such key drivers. Furthermore, they stress the fact that LMT plays a significant role as a "carrier industry" by incorporating new technologies into the making of new products or implementation of new manufacturing processes.

This debate will be taken up by focusing on the following research questions: first, are there typical innovation strategies pursued by LMT companies with regard to their main objectives, primary business area and development paths? As outlined more precisely later, the empirical bases for this analysis are the findings of a larger number of qualitative company case studies. Second, which internal and external conditions must companies fulfil to pursue successful innovation strategies? It will be explored to which extent factors like the company's knowledge base, the management capabilities and organizational structures, as well as the company's linkages and relationships to external knowledge providers and other organizations influence its innovation ability. Third, how do societal and institutional regulations affect the innovation strategies of LMT companies? This question probes into the patterns of embeddedness of LMT companies in their societal environment. Fourth, how can the findings of the analysis be incorporated into a model which represents a LMT innovation mode? To hone the model of a LMT innovation mode, it will be contrasted with research findings regarding innovations in high-tech and medium-high-tech sectors.

This paper is accordingly structured as follows: in Section 2, the research design, that is, the analytical approach and the methodological base of the study, will be summarized. In Section 3, typical LMT innovation strategies are outlined, and in Section 4, the internal and external company conditions are elaborated. Section 5 deals with the relationship between societal and institutional conditions and LMT innovations. In Section 6, the LMT findings are contrasted with typical features of high-tech innovations and Section 7 draws conclusions that revert to the introductory research questions.

2. Research Design

In order to deal with the research questions in a systematic way, the technological aspects have to be linked to socio-economic structural characteristics. The argument is that the combination of technological and socio-economic dimensions reveals general principles of a LMT innovation mode beyond the specifics of individual companies. As is well known, this perspective is suggested by the recourse to the innovation systems approach that emphasizes the systemic and evolutionary character of innovation processes, which are strongly influenced by the structure of society.[3] In this context, the concept of sectoral systems of innovation may be of particular interest as it emphasizes that innovation greatly

[3] Cf. Freeman (2002), Malerba (2004a), Edquist (2005) and Carlsson (2006) as well as the instructive summary of technology research oriented on the theory of institutionalism by Werle (2003).

differs across sectors since it links dimensions which can be considered relevant for the analysis of an economic sector (cf. Malerba, 2004, 2005): firstly, this pertains to the dimensions of knowledge, organizations and networks. According to this approach, especially knowledge plays a central role for the intensity and the process of innovations, the organization of innovation processes and the capacity to act of the organizations and particularly of the enterprises involved. An innovation system can, therefore, be characterized by the special features of its knowledge base. Relevant aspects in this connection are various forms of knowledge and their specific sources that merge into different knowledge domains. Firms that are characterized by specific process and organization structures, competencies and strategic goals and which moreover to a greater or lesser degree exchange information with further actors such as customers, suppliers and advisors and with organizations such as financial service providers, science and political institutions and sometimes form networks, are considered as the central actors of an innovation system. It is presumed that this exchange aims at the transfer and the genesis of knowledge which is essential for the technology development and the commercialization of innovations. Secondly, institutional regulations and constellations of the societal macro level, which influence the action possibilities and aims of innovating enterprises as well as exchange processes between them, are regarded as constitutive features of innovation systems. Specifications are geared towards relatively concrete societal conditions that influence innovation courses (cf. Lundvall, 1992: 13; Freeman, 2002: 194): the forms of regulations of the labour market and the institutions of the education and training system, the institutional structure of the research and science system, the economic structure that has evolved over time and the rules and standards of the public innovation and technology policy.[4] In this context, the term ''technological innovations'' will be interpreted following the socio-scientific debate on innovation tracing back to Schumpeter (e.g. OECD, 1997: 10; Fagerberg, 2005: 4). Innovation is accordingly in principle perceived as an activity which includes R&D activities, the development and successful marketing of new products, the introduction of new production technologies as well as the reorganization of processes.

The analysis is empirically based on the findings of case studies in 43 LMT industrial enterprises in nine EU countries that were conducted from mid-2003 to mid-2004 in the context of an international research project—called PILOT.[5] The specification of the individual sectors, from which the case study enterprises were chosen, was based on a statistical evaluation of the research field. Because of the heterogeneous character of LMT industries this evaluation aimed at a reasonable understanding on the LMT sector on which the research should focus. In particular, the importance of individual LMT sectors in terms of growth and employment had to be identified to find reasonable criteria for the selection of case study companies. About half of the case study enterprises were chosen from the

[4] Undoubtedly, the concept of innovations systems leaves open many questions due to its generality and unclear theoretical foundation (e.g. Bruun and Hukkinen, 2003; Werle, 2003). Nonetheless, the mentioned connections and factors provide indications of central analysis dimensions and their interrelations. Therefore, one can by all means draw on this approach as a useful analytical heuristics for the investigation of LMT innovations.

[5] This research project had 11 partners from nine European countries. Its title is ''Policy and Innovation in Low-Tech Industries in Europe—PILOT''. It was funded by the EU within Framework Programme 5. The project was coordinated by the Chair of Economic and Industrial Sociology of the University of Dortmund and ran from December 2002 until January 2006 (cf. www.pilot-project.org). The main findings are summarized in Bender *et al.* (2005) and Hirsch-Kreinsen *et al.* (2006).

Table 1. The PILOT case studies

	LMT sectors				
Number of employees	Paper & pulp	Textile	Food	Wood & furniture	Metal
1–50		1	1	1	5
51–100	3	1	2	2	6
101–250	1		1		6
251–500		1	1	1	5
>500	1		1		3
Sum (N = 43)	5	3	6	4	25

sector of metal processing and the other half from the sectors of food industry, textile and clothing industry, print industry as well as from the manufacture of wood products and paper (see Table 1).[6]

The case study enterprises had to be of a minimum size (more than 40 employees) and were chosen on the basis of criteria which proved them to be economically successful and technologically innovative. Generally, the sample primarily included small and medium-sized enterprises (SMEs), reflecting the fact that the LMT sector in Europe is dominated by enterprises of this size (CIS, 2004: 40). To allow for the comparability of the investigation results, the common methodological basis of all case studies was a standardized questionnaire and a structured interview guideline. The standardized questionnaire aimed at collecting basic data of the enterprises, for example, on product and process structures, personnel structures, customer and cooperation relations. The structured interview guideline follows the dimensions of the concept of sectoral systems of innovation and parameterizes them for the empirical analysis. On the basis of the structured interview guideline, around half a dozen interviews per case study were conducted with company experts from different hierarchical levels and from different functions. The expert interviews were supplemented by a company tour and the analysis of accessible company documents. The analytical focus of the investigation was on the innovation activities and processes, the organization and the in-house and external conditions of technological innovations of LMT companies. To sum up, the following empirical analysis is guided by the concept of sectoral systems of innovation, whose dimensions render it possible firstly to specify the introductorily mentioned research questions, secondly to systematically compare high-tech and LMT innovations and thus, thirdly, to detect a LMT innovation mode.[7]

[6] According to the sector classification NACE, this involves the following individual sectors: "Manufacture of fabricated metal products, except machinery and equipment" (DJ.28), Food, beverages & tobacco (Subsection DA), Textiles, apparel & leather (Subsections DB and DC), Wood products (Subsection DD) & furniture (DN.36), Paper, paper products & printing (Subsection DE).

[7] In the following, we refrain from a comparison with the service sector. Despite a comparison is obvious it was not treated in the PILOT project. It can, however, be surmised that there are great similarities between the LMT innovation mode and innovation processes in important service sectors (cf. Toivonen and Tuominen, 2006).

3. Innovation Strategies

The first research questions aim at typical innovation strategies of LMT companies. Following Whitley (2000: 865), different innovation strategies will be understood as combinations of enterprises' preferences, activities and capabilities for generating and diffusing varied kinds of innovation. They reflect contrasting approaches of dealing with technological uncertainties and market demands. The differences in innovation strategies are more or less closely linked with the companies' knowledge base, staff and organizational competences and the institutional environment—in a nutshell, with the main dimensions of an innovation system as outlined above. Putting it in more empirical terms, on the one hand, the term ''strategy'' reflects management decision-making processes and the various actors inside and outside an enterprise influencing it. On the other hand, technological, organizational and environmental conditions impinge upon decision making. In other words, management decisions can be regarded as the ''driving force'' of innovation strategies, however, they also reflect the enterprise's internal and external structure, particularly its traditions, power constellation, organization structures and former ''technological trajectories'', which are constraints and opportunities for decision making (cf. Child, 1972; Scott, 2001).

In terms of their priorities and objectives, LMT innovation strategies cannot at first be distinguished from those that can also be found in industrial sectors with a markedly higher R&D intensity.[8] At a second glance however, two distinctions between innovations in LMT and in high-tech sectors should be stressed here already (cf. Section 6): first, innovations of high-tech firms are nearly inevitably more technology oriented than those of LMT enterprises because of the former's running investments in R&D activities, making the role of technology more explicitly central to commercial success; that is, managerial decision making is necessarily linked to these structural conditions. In contrast, LMT enterprises need a broader variety of technology-oriented and non-technology-oriented strategy choices because of their well-established and highly competitive markets (Tunzelmann and Acha, 2005: 415). Second, following up on categories taken from innovation research, one can establish that the LMT innovation strategies move within a spectrum that is, on the one hand, bounded by the type ''incremental'' innovation and, on the other hand, by the type ''architectural'' innovation (Henderson and Clark, 1990). Following this perspective, incremental innovations are characterized by the fact that a certain product design is partially developed further by improving individual components without materially changing the overall design. Furthermore, there is usually no need to change the enterprises' organizational routines. The term ''architectural innovations'' on the other hand denotes the recombination of existing components in order to obtain a new product design or a new technical and organizational structure of the production process. In the process, the well-established technological development path is not left but often a remarkable flexibility is required as regards the restructuring of organizational routines (Whitley, 2000: 866). Both types, incremental and architectural innovations, have in common that they use given technological core concepts and knowledge assets and develop these further within the framework of the therewith chalked out development paths.

[8] Cf. for instance, the summarizing presentation of innovation processes from different sectors with a high R&D intensity by Jürgens and Sablowski (2005) or the examples of sectoral system analysis in Malerba (2004a).

They thus differ fundamentally from "radical" innovations which transcend given technological concepts and which are in many (by no means all) cases regarded as typical for high-tech sectors. These correlations can be convincingly proven by means of the empirically observable innovation strategies of LMT companies. Three typical innovation strategies can be distinguished, which centre on the development of products, on customer-oriented marketing concepts and on new process technologies (see Table 2).[9]

A first innovation strategy is characterized by the continuous further development of given products. In this case, individual product components are improved and changed regarding their material, their function and their quality but the structure and the technological principles of the products remain unchanged. This innovation strategy can be referred to as *step-by-step* product development. Typically, this concerns enterprises that manufacture products for relatively stable market segments, such as, for instance, a manufacturer of punched or sintered components for special applications in the automotive industry. The products are more or less technologically mature, they are made in big production runs and are characterized by low complexity. The process technologies that are employed in these cases often remain unchanged for longer periods of time and are at best gradually adapted to changed product requirements. Seventeen of the 43 analysed LMT enterprises to a greater or lesser extent embarked on this innovation strategy. Generally, as suppliers for the automotive industry, these enterprises mostly belong to the industrial subsector of "manufacture of fabricated metal products"; some others belong to the subsector of "wood products & furniture". More generally, this innovation strategy can be regarded as typical for industrial sectors with mature technologies and products. Not only are the markets well defined, but the products are also well established, and often standardized; production technology is efficient and the price of products is a main factor in competition. Furthermore, change is costly in such established production systems (cf. Abernathy and Utterback, 1978). Generally it can be stated that this step-by-step strategy has the typical character of an incremental innovation in the above-mentioned sense.

A second innovation strategy that could be identified is characterized by innovation measures that are directed at securing and improving the sales market situation of the enterprise. This, for instance, holds good for the fashion-oriented design of products, the functional and technical upgrading of products, a rapid response to changing customer wishes, taking advantage of market niches, skilful branding strategies and the expansion of product-related service activities. Unlike the first strategy type, the enterprises pursuing this strategy belong to a relatively broad range of industrial subsectors. Concrete examples for this strategy are company activities from the textile and clothing industries and from furniture and leather goods manufacturers whose product development is geared to anticipatable fashion cycles and whose existing product lines demand a more or less continuous variation. A further example in this respect is an office furniture manufacturer who at very short notice accepts the order of a big retailer with much market power for a large number of speedily to be supplied pieces of office furniture of a new, not previously produced type and who correspondingly diversifies his products. In various cases, one can also ascertain a broadening of the spectrum of offers as companies supplement their

[9] It need not be emphasized that this typing involves analytical exaggeration. Empirically, the different types can overlap and a clear assignment to the types is not possible in each case.

process functions with service offers and logistics services tailored for certain customers. And finally, there are reports on the growing significance of so-called B2B Internet portals which speed up and simplify the contact with important customers. According to the available empirical findings, such direct and specifically customer-related innovation activities are gaining in importance in 13 companies. In a nutshell, this innovation strategy can be referred to as a *customer-oriented strategy*. In general, it can be argued that the customer-oriented innovation strategy is a good example for the above-mentioned type of "architectural innovations". This strategy is based on the rearrangement of almost unchanged product components and units to new products and thus does not only meet special customer requirements but also opens up new market segments.

One has to distinguish between product-related and process-related innovations. Although it is often difficult to separate both aspects empirically, as product innovation often calls for changed process structures, there are, however, a whole series of companies whose innovation endeavours are primarily directed at their technical organizational process structures and which partly employ ultramodern, automated and capital-intensive process technologies. This third type of innovation strategies shall be referred to as *process specialization*. The enterprises pursuing this strategy belong to industrial subsectors with products mostly manufactured on a relatively high level of automation and of integrated process technologies. An example for this strategy is the furniture industry which is extensively automated on the basis of a significantly reduced variety of parts and of simplified processes. A second example is the continuous development of processes in woodworking which has, according to the experts, in the meantime achieved an extremely high level of process performance and process precision that is hardly comparable to other industrial sectors. Similar trends could also be discerned in sheet forming companies and firms manufacturing plastic parts, mechanic components or parts made of aluminium. A third example that can be mentioned is paper manufacture and the intricate processes in the food processing industry in which technologically elaborate processes are continually being optimized and developed further. Furthermore, under these technical and organizational conditions, the safeguarding and constant improvement of the product quality is achieved quasi as a by-product. Apart from processes with a high technological level and automation degree, these innovation activities also comprise processes with relatively simple standard techniques which are continually being "cultivated". From the sample of analysed enterprises, 13 can be assigned to this strategy type. It comprises both the ongoing technical and organizational optimization of existing production processes and also their structural reorganization on the basis of existing technologies. To put it in general terms, it has features of an incremental as well as of an architectural innovation.

However, in order to describe the LMT innovation mode in a more precise and detailed manner, the additional aspects such as knowledge, organizational structures and managerial capabilities have to be taken into consideration too.

4. Internal and External Company Conditions

4.1. Knowledge Base

The second research question of this paper is directed towards the internal and external conditions for LMT innovations. Based on the innovation systems approach, the knowledge

Table 2. Characteristics of different types of LMT innovation strategies

	Step-by-step	Customer oriented	Process specialization
Primary subject area	Incremental product development	Improving the market position; creating new markets	Optimization of process technologies
Example	Supplier for the automotive industry	Fashion-oriented clothing and furniture industries	Paper manufacturing and food processing
Main conditions	Companies with relatively stable market segments	Broad range of various companies with turbulent market conditions	Companies with highly automated and integrated manufacturing processes
Number of case studies	17 cases	13 cases	13 cases

base emerges as one of the most fundamental preconditions. For an analysis of the knowledge base of the enterprises discussed here, one has to act on the assumption that these enterprises pursue virtually none of their own R&D activities. It therefore stands to reason that formalized processes of knowledge generation and use only play an insignificant role and that instead innovation activities proceed in the form of "practical and pragmatic ways by doing and using" (Tunzelmann and Acha, 2005: 417). In a general perspective, the knowledge that is relevant for these enterprises shall therefore be regarded as application-oriented practical knowledge. Unlike scientifically and theoretically generated knowledge that orients itself on criteria such as theoretical relevance and universality, practical knowledge is generated in application contexts of new technologies and obeys validity criteria such as practicability, functionality, efficiency and failure-free use of a given technology. Both types of knowledge are, however, difficult to distinguish. Simplifying matters, theoretical and scientific knowledge in enterprises, for instance, in the form of systematically acquired engineering knowledge, can primarily be assigned to research, development and construction processes while practical knowledge accrues in the context of ongoing operating processes. The term "practical knowledge" stands for a complex bundle of different knowledge elements that comprises both explicit, codified and formalized elements such as, for example, design drawing and requirement specifications for new products as well as, above all, implicit elements such as accumulated experience and well-established and proven and tested routines for solving technical problems. The latter are closely connected with everyday experience and processes of "learning by doing" and "learning by using" which constitute a typical individual but also collective form of acquisition of practical knowledge.[10]

An example in this respect is the innovation strategy of process specialization. On the one hand, the enterprises considered here make use of engineering knowledge that is incorporated and codified in the production facilities and their operating instructions, on the other hand, specifications and ongoing intervention and adaptation measures are

[10] Similar correlations are indicated by Nonaka and Takeuchi's category "operational knowledge" (1997: 70), which describes the process of integration ("internalization") of explicit and codified knowledge into ongoing operating processes that are strongly characterized by tacit knowledge.

necessary. An indispensable precondition for this is the practical knowledge in various forms gained in the operative process, thus, for example, about the shortcomings of and problems with the applied production technologies and about their effective technical, organizational and, of course, economic application and utilization potentials. Process innovations generally take place in the context of the ongoing operative processes and are potentially initiated and at any rate pressed ahead with by the staff responsible for the ongoing functions, such as engineers, technicians, master craftsmen and qualified workers. Similar innovation processes which, for example, entail the stepwise introduction and adaptation of new production and logistics techniques under the direction of the management and occasionally with the active participation of the production personnel, are also observable in the case of the customer-oriented strategy.

The acquisition and generation of innovation knowledge by no means takes place only within the company. Rather external knowledge sources prove to be relevant too. For all innovation strategies, the knowledge of other firms, organizations and other actors as well as its systematic use for the innovation measures pursued plays a decisive role. This is true for both practical knowledge and especially also for scientifically generated knowledge in various forms. Examples for external sources, for instance, in the case of the customer-oriented strategy, are the experience of long-time customers concerning new market and demand trends, the expertise of pertinent consultants or information about foreseeable market trends gained during fair visits. Furthermore, the fashion-oriented design of products, for example, of chairs, by external design agencies plays a far from marginal role for successful sales strategies. Further important external knowledge sources are machine manufacturers and suppliers who provide theoretically and scientifically generated knowledge in the shape of knowledge incorporated in production technologies and materials, which is often an essential prerequisite for the innovation activities of process specialization. A similar procedure can be observed in the case of the step-by-step strategy of product improvement which is often triggered by systematically generated specifications of corporate clients, for example, from the automotive industry. A similar example is the specification of material parameters by material suppliers that are taken over by the producers and are systematically used in the course of the further development of the products. On the whole, the knowledge base of non-research-intensive enterprises can be characterized as a ''distributed knowledge base'' (Smith, 2003), that comprises the different forms of knowledge of actors who are independent of each other and often come from different sectors and technology fields. The empirical findings suggest that the main source for the knowledge generation of the LMT companies lies here.[11]

4.2. Management of Internal Knowledge

Of decisive importance for the innovation strategies of companies is moreover the manner in which they effectively make use of their internally available as well as externally accessible knowledge. The innovation systems approach regards the organizational

[11] There are considerable similarities between the outside-oriented innovation activities of LMT companies and the principles of the ''open innovation'' concept (cf. Chesbrough, 2003). It can be indeed stated that LMT companies are due to their limited in-house innovation capacities inevitably early adopters of this concept (Chesbrough and Crowther, 2006) (thanks to an anonymous referee).

structures and the internal processes within the companies as one of the determining factors in this respect. This connection can be specified by reverting to the concept of "dynamic capability".[12] What is meant by this is the ability that enables companies to cultivate and develop their knowledge base strategically, to mobilize it and, in doing so, to combine the individual knowledge elements in specific ways in order ultimately to generate technological innovations. In the case of the non-research-intensive sector, this can be qualified as follows:

- Firstly, it involves the ability to use and to advance the knowledge that is in principle already available in the context of product and process innovations; that is to say continually to transform this knowledge. In the described case of the step-by-step product innovation strategy, this ability plays a decisive role regarding the modification of specific product functions, for instance.
- Secondly, it concerns the ability continually to recombine available knowledge and technology elements in order to realize enhanced products and process structures.[13] This ability is of particular importance, for example, in the case of the customer-oriented strategy and the "architectural" reassembling of at best partially further developed product modules into a new product design.
- Thirdly, this addresses a further dimension which denotes the ability to integrate new knowledge. This relates to the fact that a number of the companies examined more or less continually take up new, generally externally generated knowledge,—be it practical experience of the sales personnel about completely changed marketing conditions or research results from engineering science concerning new machining procedures or potential product materials—integrate it into their existing knowledge base and develop new products and processes on this enhanced basis.

This ability to utilize knowledge is to a large extent dependent on the routines and structures of the company organization, for instance, the mode of the division of labour, the prevailing communication and cooperation forms and the therewith connected qualification and personnel structures (cf. Cohen and Levinthal, 1990: 131; Henderson and Clark, 1990: 15). Relating to the different innovation strategies, however, only few distinct connections could be empirically observed: in some cases the management attempts to approach product and process innovations strategically by defining development projects with a certain priority and by setting up target agreements together with the few engineers and master craftsmen in the staff. In other cases, for instance in those of fashion-oriented clothing manufacturers pursuing a customer-oriented strategy, one can find relatively well-established procedures that generate product ideas within the context of the ongoing production process itself. These procedures have been well rehearsed in the course of the years. Besides the above-mentioned cases, there are also many enterprises in which innovation ideas resulted from random trial-and-error processes or could often also be ascribed to the ideas of individual

[12] Putting it simply, the central argument of this resource-oriented analysis concept (e.g. Dosi *et al.*, 2000) stemming from management research is that enterprises are characterized by a specific combination of special and rare resources, especially of knowledge of different kinds and that they have to possess a specific ability, designated as "dynamic capability" to be able to use these resources for their strategic objectives (Bender and Laestadius, 2005; Laestadius, 2005).

[13] Following Kogut and Zander (1992), who speak of a "combinative capability".

managers, technicians or salespersons. Aspects such as sufficiently open channels of communication, some room to manoeuvre and specific slack times at least for certain employees, but also corresponding impulses and targets on the part of the management that aim at promoting the target-oriented mobilization of the available knowledge, can be regarded as constituting crucial personnel and organizational conditions for the effectiveness of these practices.

In most of the enterprises, these practices are embedded in a company and work organization form that is centralized and based on a marked division of labour (cf. Schmierl and Köhler, 2005). In the majority of the companies, one can observe a concentration of the knowledge in the hands of a small group of managers and technical experts while the more or less qualified production workforce is only responsible for carrying out tasks. In many cases one can speak of the dominance of Tayloristic forms of work organization which are, however, often—as in the case of enterprises which can be assigned to the problem-solving strategy—accompanied by a flexibilized staff deployment as regards working hours and the workplace. Only in some of the enterprises, especially if they belong to the strategy type of process specialization, can one observe qualification and holistically oriented forms of work organization which allow a regular workforce of skilled technical staff much leeway for decisions and room for manoeuvre. For only thus can the experience potential of the workforce be used for the continuous innovation of the process technologies and can costly machine downtimes during ongoing operations be avoided.

4.3. Management of the Distributed Knowledge Base

Following the case study findings, the ability to manage and effectively coordinate network relations across company borders, especially with other companies within the value chain, is a central precondition for successful LMT innovation strategies too. An essential requirement for the efficiency of such relations is a company organizational structure that is geared to the demands of cross-company cooperation by, for example, providing for adequate channels of communication, gateways and personnel responsibilities geared to cooperation. A further important aspect in this respect is the professionalism of the management. It has to be able to harmonize and to control the specific competencies and the therewith associated interests of many different cooperation partners in such a way that the transfer of the required knowledge is assured. And as network research findings (e.g. Semlinger, 2003) also show, especially the management's ability to communicate intensively regarding both everyday matters and strategic aspects of cooperation is of great importance in this connection. Therewith the foundation is laid for continually attending to the state and the development of cooperation relations, for overcoming restraints and barriers and for creating the necessary reliability.

If one, to become more concrete, begins by looking at the suppliers of LMT enterprises, one can distinguish a whole spectrum of different types: firstly, there are the suppliers from different sectors and with specific competencies who reliably, flexibly and especially cost-savingly supply simple and standardized preliminary products and product components. With regard to innovation strategies, such standard suppliers are in so far of significance, as their ability to supply and above all their prices possibly have a decisive influence on how successful a customer-oriented strategy really is, on how smoothly and quickly new sales potentials can be opened up and on whether the planned product innovations are possible

with the available parts and components. Secondly, there are also the—sometimes referred to as "strategic"—suppliers who by virtue of their specific knowledge of materials, production possibilities, etc. give important impulses for the further development of low-tech products and who can compensate the knowledge deficits of the respective enterprises. Typical examples are suppliers of specified materials such as special steel and print colours or of machine components as well as of devices that are indispensable for the innovation of products. As in the case of chemical industries or machine building companies, for instance, this often concerns suppliers from high-tech sectors whose services are an indispensable condition for both step-by-step innovation strategies and innovation strategies of process specialization.

With regard to the relations of these companies with customers and purchasers, the constellations are likewise very diverse. On the one hand, the enterprises, especially if they are characterized by the customer-oriented strategy, pursue an active market strategy that focuses on the direct access to end customers by means of well-established distribution channels and long-term connections. To achieve this, detailed information about changing customer preferences and sales strategies of big retailers is, as already mentioned, vital for sales successes and for the companies' ability to detect new sales opportunities, market niches, etc. and to avail themselves of these by means of, for instance, product modifications. On the other hand, one can identify market activities with which the enterprises merely react to the requirements and impulses for certain product innovations that come from powerful corporate clients. This is, for example, the case for enterprises with a step-by-step product development strategy who realize the general specifications predetermined by the end producers in the form of product modifications. Normally, these product specifications have to be accepted and realized by the non-research-intensive enterprises without modifications or adaptations to their own product and production conditions. In these cases one can observe the familiar pattern of power asymmetrical supplier relations that to a large extent determines the innovation strategies of non-research-intensive enterprises. This situation can, however, to all intents and purposes also implicate that these enterprises permanently profit from the innovation impulses and the therewith transferred knowledge of their dominant corporate clients as the restrictions of their own innovation conditions are thus overcome. For the oftentimes smaller partner, the reliability of the larger partner can be an important resource, perhaps even a survival guarantee; at any rate it saves him costs for which he would potentially have to raise money if the cooperation relations were lacking.

5. Societal and Institutional Conditions

The third research question of this paper deals with the embeddedness of LMT innovation strategies in societal and institutional conditions. By taking a closer look at these conditions, the specifics of LMT innovation strategies can be stated more precisely. If one follows the innovation systems approach, this especially pertains to those socio-institutional conditions that are evidently linked to technology development and innovations. The available empirical material on LMT innovations, however, points to the differing significance of these connections. They can be positioned in a broad spectrum of couplings between the innovation strategies and the societal institutions which differ in intensity.

5.1. Loose Coupling with Vocational Education and Innovation Policy

Only a small number of enterprises regard the conditions of the labour market and the institutions of vocational education and training as relevant for their innovation ability. This aspect is particularly emphasized by enterprises pursuing the strategy of process specialization. These enterprises employ the most modern production technologies and they therefore need sufficiently experienced and competent manpower for the continuous operation of the often complex robotized lines. In this respect, especially bottlenecks and restrictions because of the difficulties of recruiting employees with specific qualifications are addressed. Above all, the enterprises refer to lacking so-called hybrid qualifications that encompass both traditional technical and professional competencies as well as skills relating to new technologies and organization forms. Furthermore, the strategy of process specialization leads to organizational changes such as hierarchy reduction, the introduction of teamwork and the deployment of qualified labour. This calls for qualifications that are, for instance, described with key words such as communication skills and the ability to work in teams and that are not always available on the labour market. This issue of qualification deficits is raised by many enterprises, irrespectively of whether they can fall back on trained skilled workers as in Germany or on academically qualified staff as in Scandinavia or in Ireland. They emphasize the fact that the contents of vocational training do not always correspond to the actual requirements of the new technologies and new organization structures and that therefore additional and costly training courses and processes of continuous further training and education are often necessary.

For the enterprises pursuing customer-oriented and step-by-step strategies, however, the institutions of the labour market and of the system of vocational education proved to be of little significance for their innovation ability. For many of the non-research-intensive enterprises bundle their internal knowledge in the hands of a few managers and experts while the majority of the employees are more or less semi-skilled workers. Obviously this hardly entails special recruiting or qualification problems and these companies are therefore virtually not dependent on processes of socially regulated qualification acquisition. At best, as in the case of the step-by-step strategy, enterprises' representatives express their interest in unskilled but quickly trainable and motivated manpower such as, for example, migrants, whose employment rights and possibilities are subject to too many restrictions from their point of view. In so far, the examined companies are in many cases part of a labour market that approaches the type of an unstructured labour market while the regulated structures of a professional or even an internal labour market are irrelevant.

Similar connections can be made out with regard to the importance of political regulative stipulations for the innovation strategies of LMT (cf. Jacobson and Heanue, 2005). Regardless of the type of strategy, LMT companies pointed out decidedly negative political factors such as high costs, particularly labour costs and taxes, or an inflexible and restrictive state bureaucracy. There is certainly no denying that these aspects can be very serious for many LMT enterprises because of the intensive cost and competition pressure. For another thing, particularly enterprises pursuing the strategy of process specialization on various occasions referred to the existing public promotion of technological innovations and the state-aided extension or even start-up of factories as innovation-promoting conditions. Sure enough, these promotion measures are often laid out in a sector-unspecific way or they aim at the support of research and high technologies and not at the specific concerns

of low-tech enterprises, a circumstance that is often referred to as "lacking awareness" of innovation and economic policy actors towards the needs of non-research-intensive industries. At best, such measures indirectly promote the innovation ability of LMT companies, in so far as they are generally directed at the improvement of the technological and economic conditions of industrial production.

The same can be observed at the level of EU-technology policy. But here the focus on research and high technology is even more pronounced than at the national level. This applies to the different EU-wide support programmes since the beginning of the 1980s as well as to a programme such as EUREKA (European Research Coordinating Agency), that is primarily geared to coordinating different national businesses and organizations. In either case, the objective is to promote R&D activities and to initiate as far-reaching basic innovations as possible and to leverage them. However, according to the available findings, non-research-intensive innovations are likewise neglected in these programmes.

5.2. Tight Coupling with the Given Economic and Industrial Structures

Given the described importance of the distributed knowledge base for the innovation ability of the LMT enterprises, it is, however, not surprising that the companies' embeddedness in the economic and industrial structures around them in many cases proves to be a relevant condition for their ability to innovate. As already mentioned in the context of the positioning of non-research-intensive enterprises in the value chain, this concretely involves networking with "neighbouring" and "supporting" companies and organizations who, as the case arises, provide new technologies and knowledge (Porter, 1998: 166). This aspect is firstly emphasized in the face of the pronounced concentration of suppliers in many West European countries, as this allows manufacturers—depending on their innovation and production requirements—more easily to change suppliers than in less industrialized countries and thus flexibly and quickly to adapt the value chain to new requirements. Particularly enterprises pursuing a customer-oriented strategy profit from this situation due to their market-driven flexibility needs. Secondly, this connection is of importance for enterprises with a process specialization strategy. Close relations to the developers and manufacturers of production technologies are crucial for them. This holds good particularly if technical equipment is custom designed, or if at least certain components and functions are adapted to the particular user needs. Naturally this presupposes relatively close coordination, communication and learning processes between the partners concerned. These findings fit well with the general results of the study based on statistical data by Nascia and Perani (2002) on innovation in Europe. They have shown that the scientific and technological environment where an enterprise is located has relevant effects on the enterprise's ability to use existing and available knowledge.

Thirdly, service providers with specialized knowledge occasionally play an important role for the innovation strategies of the companies. In this regard one can, for instance, mention design companies that assume responsibility for parts of the product design, firms or institutes that have special competencies and facilities for quality tests or for special technical development questions at their disposal as well as market research institutions. One can often come across such cooperation relations in the case of the customer-oriented strategy. Sometimes specialized research institutes are also assigned development tasks such as, for example, material tests or material calculation for a step-by-step innovation

strategy or, in the case of process specialization, the design of installations. They furnish the engineering knowledge which is necessary for low-tech innovations. And finally, the companies occasionally draw on consultants, for example, for solving problems of process development and optimization. Altogether, the forms of exchange between the different actors of the distributed knowledge base can be very diverse. They range from a relatively anonymous market-regulated exchange to well-established and intensive cooperation relations.

Furthermore, the tight coupling of the LMT enterprises with companies and organizations from R&D-intensive sectors is crucial for their innovation ability. This in particular concerns the above-described exchange relations with supporting companies as well as with the developers and manufacturers of complex process technologies, with the aforementioned service providers and also with scientifically oriented institutions which partly make new knowledge and technologies available in the context of close cooperative relations. But in this case, tight coupling also means that relevant innovation impulses are given in the reverse direction—from ''low-tech'' to ''high-tech''. These impulses result from the simple but often overlooked economic circumstance that the profits from the sold new technologies are a vital condition for the amortization and for the continuation of R&D investments on the part of the research-intensive enterprises. A determining factor in this respect is the rapid diffusion of new technologies, which is in turn very strongly influenced by the respective dynamic capabilities of the non-research-intensive companies (Robertson and Patel, 2007). Secondly, they result from the companies' technical and economic specifications of application requirements for new technologies. Again, LMT enterprises with a strategy of process specialization play a decisive role in these relationships. They very often influence the development directions of new technologies if the requirements of individual users converge with those of as many other users as possible and thus, from the manufacturer's point of view, a broad application field for complex products is opened up. As examples, one can cite the process technologies in woodworking and in paper manufacture, whose continuous further development, to be sure, is initiated by individual users but at the same time this development maintains and creates industry-wide and intersectoral marketing and application opportunities.[14]

5.3. Erosion of Regional Ties

This tight coupling with the surrounding economic and industrial structures nonetheless does not mean that the regional embeddedness of LMT enterprises is on all accounts relevant for their ability to innovate. Therefore, the empirical findings at hand can only be subsumed under a few general development trends and it seems advisable to take up the thesis of the ''paradoxes of territories'' that comes from the socio-scientific regionalization and globalization debate (Crouch *et al.*, 2001: 21): on the one hand, many LMT companies are under pressure to spatially extend their cooperation with suppliers and furnishers as well as to expand their customer relations in order to secure and partly improve their positions. This holds true for enterprises pursuing a step-by-step strategy, for instance, suppliers for

[14] In innovation research, this phenomenon of the generalization of certain technologies is understood as a process of ''technological convergence'' between different companies and sectors of industry (Rosenberg, 1963).

the automotive industry. They often have to relocate production sites due to cost pressures and the proximity to their huge customers. Furthermore, enterprises with a customer-oriented strategy are also relocating their production sites to an increasing extent due to cost pressures and intense international competition (cf. Garibaldo, 2006). As a result, existing markedly regional industrial agglomerations such as the well-known industrial districts in the Emilia Romagna are threatening to erode. The changing patterns of spatial proximity less and less frequently feature the tightly networked and insular relations structures and coordination forms of a comparatively closed regional innovation and production system. According to the available findings, market-regulated and contractually formalized exchange relations that are increasingly far removed from the region and are characterized by an increasing cost competition are in fact gaining in importance (cf. Garibaldo and Jacobson, 2005).

On the other hand, "going global" implicates a growing importance of spatial and therewith connected social and cultural proximity for the general strategy ability of the enterprises, as these bring about specific operative advantages over competitors: particularly for enterprises with a customer-oriented strategy, spatial proximity is regarded as important for supplier relations, as logistic problems can thus be avoided and the rapid availability of parts and components is thus guaranteed. In many cases spatial proximity also plays an important role for customer relations as thus, most notably, the ability to deliver overnight is guaranteed. Furthermore, for a number of enterprises following the strategy of process specialization, the proximity to the manufacturers of production technologies plays an advantageous role due to the mutual information and communication basis associated with it.

In addition, aspects such as regionally established occupational training and further education institutions, which are credited with an important supporting function particularly by process specialists with their special qualification needs, must be mentioned. As the training imparted by these institutions is often geared to the needs of the regional LMT companies with highly automated production technology, a relatively trouble-free and fast recruitability of correspondingly qualified staff is thus guaranteed. Finally, for some enterprises—regardless of the strategy they pursue—regionally established and accordingly specialized scientific organizations, technology liaison offices, political institutions, associations, chambers of commerce and industry or also regionally focused support programmes play a certain role too for their innovation ability. For such actors and activities oftentimes provide knowledge that can initiate company leaning processes which can lead to concrete innovation measures.

6. LMT Innovation Mode versus High-Tech Innovations

The outlined empirical findings on LMT innovations were integrated into a model of a LMT-specific *innovation mode*. Theoretically, this innovation mode can be seen as the product of enterprise strategies that reflect their organizational capabilities and strategic priorities, which in turn interact with their economic and institutional environment (cf. Whitley, 2000). In this view, the special features of the LMT innovation mode can be summarized as follows: as already emphasized by Tunzelmann and Acha (2005), the key innovation drivers are changing technological paradigms and demand differentiations. These factors have to be regarded as essential (pre-)conditions for the innovation courses of LMT enterprises.

Sufficient conditions for successful innovation strategies are how companies deal with these requirements and potentials based on their specific managerial and organizational capabilities. Key features are an in-house practical knowledge in the context of a distributed knowledge base and the largely managerial based competence to make use of and to expand this knowledge. In doing so, the resources and capacities for strategic action are in the most cases limited, as the LMT sector is quite generally dominated by SMEs. Furthermore, a mostly loose coupling of the enterprises' innovation capability with socio-institutional conditions prevails. In many cases, however, the networking with research-intensive sectors plays a comparatively central role for maintaining and expanding the innovation ability of these enterprises. Finally, the phenomenon of architectural innovation can be regarded as an important characteristic of the LMT innovation mode. Architectural innovation does not only comprise the ability to combine and recombine available technology components but also the capability of taking up, adapting and using distributed knowledge for novel problem solving. Quite obviously, this allows enterprises to gain a considerable competitive edge under the conditions of an intensifying global competition, as these abilities render possible innovation strategies which enable the companies to leave chalked out step-by-step development paths in favour of a rapid product change. With regard to the generally increasing dynamics of technology, there is a growing need for LMT companies to gain access to new knowledge and technologies and to improve their capabilities to integrate them into their innovation strategies. The traditionally great significance of the above-mentioned product-oriented step-by-step innovation strategy (cf. Abernathy and Utterback, 1978) will most likely dwindle away in the light of the increasing turbulence and growing competitive pressure of the international sales markets. As recent developments show, particularly competitors from emerging economies like India and China intensively pursue this strategy at a very low cost level (cf. Cox, 2007).

The outlines of a LMT innovation mode can be honed a little more by means of a comparative perspective which probes into typical innovation aspects of the high-tech and medium-high-tech sectors (HMT). Of course, it is not easy to identify typical features of high-tech innovations due to the sector's heterogeneity. Following the available studies and findings one can at least attempt to identify the distinctions as far as the industrial HMT sectors dominating in Europe are concerned. The automotive industry, the mechanical engineering industry, parts of the telecommunication industry, the pharmaceutical and the chemical industry can be regarded as typical for Europe's high-tech and medium-high-tech sectors. In contrast to the LMT sector with its high percentage of SMEs, these industries are to a large extent dominated by huge and internationally active enterprises.[15]

The features of a high-tech innovation mode can be summarized as follows: although market demands undoubtedly play a decisive role as key drivers of innovation in this sector and its subsectors, innovations of HMT firms are nearly inevitably more technology oriented than those of LMT enterprises. As already underlined (cf. Tunzelmann and Acha, 2005), one of the main reasons for this is their running investments in R&D activities. In the past few years one could, for example, observe a high and growing level of R&D investments in

[15] Cf. particularly the sectoral studies in Malerba (2004a); furthermore, Jürgens and Sablowski (2005) and Heidenreich (2008). For a comparative analysis of the different sectors in the UK based on CIS data see primarily Cox *et al.* (2002); based on the same data and also for the UK Tether (2002) has analysed cooperative arrangements for innovation in different sectors.

mechanical engineering (OECD, 2005). Therefore, the role of technology is more explicitly central to the commercial success for HMT firms; that is, managerial decision making is necessarily linked to these structural conditions. This leads to the feature of the comparatively high relevance of radical innovations especially with a focus on product innovations (cf. Cox *et al.*, 2002). Well-known examples can be found in the pharmaceutical industry as well as in parts of the mechanical engineering industry; after the Second World War a significant group of enterprises in both industries maintained innovation strategies which heavily focused on radical product innovations. As shown by the findings of recent research studies, especially enterprises from the automotive industry have in recent years pursued innovation strategies that boil down to an enduring change of product technologies and the therewith connected corporate structures.[16]

These innovation strategies and the enterprises' specific capabilities depend heavily on new, codified science-based knowledge which has internal as well as a broad spectrum of external sources. Internal sources of new knowledge are large R&D and design departments with their highly qualified staff. External sources are tapped via close links with suppliers from different sectors, with engineering services, with consultancies, with highly specialized start-up companies and with scientific institutions. These external sources of knowledge and technology have become increasingly important for the innovation ability of HMT enterprises, irrespective of the industrial sectors they come from. The innovations discussed here typically draw upon knowledge from a wide variety of sources that transcend current boundaries (Whitley, 2000: 878). According to recent analyses, the intensity of the cooperation relations of enterprises from the HMT sector with external partners such as suppliers, customers, particularly also scientific institutions, consultants and further specialized organizations is far more pronounced than that of industrial enterprises from the non-research-intensive sector (cf. Tether, 2002). The different sizes of the enterprises can, firstly, be regarded as one of the reasons for this. The predominantly smaller companies from the LMT sector have fewer resources and capacities at their disposal for the development and management of cooperation relations than the predominantly larger companies from the HMT sector. Secondly, the higher risks and insecurities of far-reaching or even radical high-tech innovations urge the enterprises—irrespective of their sizes—to intensify their external cooperation relations.[17]

According to research findings, a key organizational competence of HMT enterprises is therefore the capacity to absorb and to integrate external knowledge, this ability is based on their extensive internal R&D capacities with a more or less large number of formally high-skilled personnel. Although codified knowledge is very important, internally accumulated practical knowledge also plays a significant role for successful innovation strategies in many cases. Convincing examples for this are process innovations in the automotive and

[16] In a comparison of the national innovation systems, sectors such as the automotive industry and mechanical engineering are often deemed to be classic European or German examples for incremental innovations (cf. Caspar *et al.*, 1999; Hollingsworth, 2000; Hall and Soskice, 2001). But recent studies show that the innovation dynamics especially in these sectors has dramatically accelerated and that the innovations can therefore—unlike the LMT innovation mode—be regarded as "radical" innovations (Jürgens and Sablowski, 2005).

[17] This is indicated by research findings from different European countries; in this context one can, for instance, cite the analysis findings of the statistical data of the European Community Innovation Survey for Germany and for the UK (cf. Fritsch and Lukas, 2001; Tether, 2002), as well as a recent Europe-wide research study on the cooperation behaviour especially of SMEs (Bluhm *et al.*, 2003).

mechanical engineering industry which are often based on the experience of skilled workers and plant engineers (cf., e.g. Jürgens, 2002). In any case, the complexity of the knowledge base of high-tech innovation strategies is remarkable, reflecting the combination of dominating codified knowledge and practical knowledge (Whitley, 2000: 871).

A further central feature of the HMT innovation mode outlined here is the pronounced coupling of corporate innovation strategies with a tightly knitted system of societal institutions that promotes technology-based and long-term-oriented innovations. The case of Germany is typical; main features are: a system of vocational education, the prevailing professional and internal labour market structures, a system of industrial relations geared to a large company core workforce and to qualified production work and close links to universities and a science system that is to a great extent dominated by application-oriented engineering sciences. Of crucial importance are also the specific structures of corporate governance which, together with the dominant outside financing, have facilitated long-term-oriented investment and innovation strategies and a public economic and technology policy aimed at these core sectors (cf. Hollingsworth, 2000). Especially the close connection between the corporate strategies and the national technology policy can be regarded as one of the central preconditions for limiting the innovation risks in the high-tech sectors. In the telecommunications sector, for instance, the governmentally influenced establishment of technical norms and standards had an important influence on the concrete course of innovations (cf. Edquist, 2003).

The general conclusion is that LMT innovations differ quite markedly from the stylized HMT innovation pattern (see Table 3).[18] One primarily has to point to its missing internal R&D capacities and its specific knowledge base, the little structured innovation processes and particularly to the loose institutional integration. Furthermore, the processes are not particularly compatible with the institutional framework of high-tech. This becomes apparent if one considers that the innovation achievements of LMT enterprises often depend on the high ability of the companies to react to market requirements, particularly by means of a flexibly deployable, semi-skilled staff. These requirements relatively quickly come into conflict with established regulations, for instance with the standardized labour policy regulations and the regulated internal and vocational labour market structures prevailing in important EU countries like Germany.[19]

7. Conclusions

The research findings on innovations in the LMT sector outlined in this paper have some interesting research implications. Firstly, the findings show that the category ''low-tech'' by no means denotes enterprises that are not innovative. Especially in comparison to high-tech enterprises, they are, in fact, innovative in a very specific way. Thus Mendonça and Tunzelmann's dictum, according to which ''innovation in low-tech industries should, therefore, not be seen as a contradiction in terms'' (2004: 15) is verified. Furthermore, this finding once more addresses the aforementioned question of the measurement of

[18] In that respect our broad case study findings on LMT innovations converge with the results of a former statistical analysis presented by Cox *et al.* (2002) on the basis of the CIS data for the UK.

[19] These findings suggest many policy recommendations which have been detailed in the aforementioned PILOT project; see Jacobson and Heanue (2005) and Hirsch-Kreinsen *et al.* (2006).

Table 3. Stylized innovation modes

	LMT	HMT
Key drivers	New technologies—market demand	Science and technology driven in combination with market demand
Typical strategies	Broad spectrum: incremental—architectural	Broad spectrum, high relevance of radical innovations, main focus on product innovations
Size of enterprises	Mostly SMEs	Mostly large enterprises
Knowledge base	Internal: high relevance of practical knowledge	Internal: high relevance of codified knowledge in combination with practical knowledge
	External: codified knowledge	External: wide variety of sources for codified knowledge transcending sectoral boundaries
Company capabilities and competences	Mostly management-based and unskilled workers; centralized competence base	Management, engineers, experts, skilled workers; broad competence base
Network relations	Cooperation with high-tech and specialized suppliers, consultants, etc., partly with customers, limited inclination to cooperate	Wide variety of external partners stemming from various societal sectors (national and international); intensive cooperation with external partners
Institutional embeddedness	Loosely coupled with most institutional conditions apart from industrial structure	In many cases pronounced coupling with societal institutions; high relevance of innovation policy

innovations and the problem of the unidimensionality of the still commonly used indicator of R&D intensity (cf. Grupp, 2008). As has become clear, this concept results in the specific conditions of the LMT innovation mode being overlooked by science and innovation policy.

Secondly, the findings strongly suggest the specification of the term "sector" and its boundaries. It has become clear that typical innovation patterns are oftentimes not restricted to sectors in the conventional sense, that is, to statistically definable industrial sectors. The comparison between LMT and HMT shows that recurring principles and similarities with respect to innovation patterns can have a cross-sectoral character. These contexts are only insufficiently grasped by the well-established approaches of the systems of innovation. This is especially true for the concept of the sectoral systems of innovation, which assumes that "The boundaries of sectoral systems are affected by the knowledge base and technologies". (Malerba, 2005: 389) As a rule, the sectors are empirically defined along the well-known statistical delineations, for example, pharmaceuticals, chemicals, software and machine tools as HMT. Undoubtedly a whole range of very instructive analyses of innovation processes follow this demarcation (cf. Mowery and Nelson, 1999; Steil *et al.*, 2002; Malerba, 2004). On the one hand, it stands to reason to analyse both LMT and HMT innovations in this traditional sectoral perspective. On the other hand, the outlined research findings indicate that the concept of sectoral boundaries has to be conceived more broadly as well as more systematically, in order to understand relevant aspects of the courses of technological innovations. To solve this problem one can refer to the concept by

Charles Edquist (2005) to define the boundaries of an innovation system in terms of ''activities''. This term refers to the causes and determinants of innovation processes like R&D, competence building, networking, etc. The main argument is that an explanation of innovation processes has to be multicausal and therefore one should specify the relative importance of various determinants and their interdependence (ibid.: 190). The above outlined LMT and HMT innovation modes can be linked precisely to this. They differ clearly concerning important causes and determinants like key drivers, their specific knowledge base, company capabilities and competences or network relations (see Table 3). These factors are not only interdependent of each other but also they support and reinforce one another. Following the sociological institutional analysis, these interrelationships can be termed as complementarity, that is, one set of the aforementioned factors is complementary to another when its presence raises the returns available from the other (Hall and Gingerich, 2004: 6). Concerning technological innovations complementarity causes more or less stable and successful development paths. In other words, complementarity can be regarded as the central feature of a specific innovation system. At the same time this feature allows to identify precisely the boundaries of an innovation system.

Thirdly, the analysis findings also point to specific relationships between the different innovation systems. It has been demonstrated that both LMT and also HMT innovations are to a great extent interdependent. This paves the way for following up Pavitt's taxonomy of technological change (1984), in which the concept of complementarities between companies with a different technological background plays a central role. As mentioned before, in this taxonomy the category of ''supplier dominated'' industries refers to this important aspect of the LMT innovation mode: technical change mainly derives from the suppliers of equipment and examples for this are traditional sectors of manufacturing such as textiles and house building (ibid.: 356). A similar line of argument is followed by Robertson and Patel (2007), who conceive the relation between LMT and HMT industries as complementarity between ''recipients'' and ''carriers'' of new technologies. Additionally, these arguments can be linked with the dictum by Kline and Rosenberg, that:

> ''… the impact of a technological innovation is often difficult to trace because those impacts do not always fall neatly within well-defined industry boundary lines. Sometimes, in fact, the effect of technological change may be to bring out a drastic redrawing of the previously existing boundary lines''. (1986: 81–82)

These aspects of complementarities and boundary crossing suggest, in a more general perspective, a revised understanding of the contemporary structural change in developed societies. It should have become clear that the debate about the emerging knowledge society with its particular focus on R&D and on high-tech-based innovations as the driving powers of the socio-economic development neglects relevant conditions and connections. The structural change can on no account be characterized as a far-reaching turning away from traditional industries with old technologies and a growing dominance of industries with complex and advanced technologies. On the contrary, this change in fact comprises LMT industries too and is primarily based on the networking between the different sectors. Under the pressure of growing international economic and technological competition, this special kind of networking will intensify.

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