PILOT

Policy and Innovation in Low-Tech

Non-science based innovativeness
– on capabilities relevant to generate profitable novelty –

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The starting point of the paper is the widely held assumption that the ability to permanently generate and market innovations is one major precondition to maintain competitiveness of European based units and thus to contribute to employment. The authors argue that R&D in the established sense is only one and mostly not the most important asset for an organisation's innovativeness. Drawing on the literature on dynamic capabilities a concept of innovation enabling capabilities is introduced. It is composed of two dimensions, transformative and configurational capabilities. The former focuses on the enduring ability of an organisation to transform globally available general knowledge into locally specific knowledge and competence, the latter on the enduring ability to synthesise novelty by creating new configurations of knowledge, artefacts and actors. Three specific aspects of configurational capabilities are established, cognitive: configuring distributed knowledge of different kind; organisational: configuring distributed actors and other repositories of knowledge and know-how; and design: configuring functional features and solutions. The distinction between transformative and configurational capabilities is strictly analytical; empirically the two dimensions are tightly interwoven. And innovations require both. The different dimensions of innovation enabling capabilities are illustrated drawing on examples from a selection of company case studies conducted during the PILOT project.

1 Introduction

One immediate consequence of globalisation is that firms in most industries – within manufacturing as well as service sectors – face tough competition from firms located all over the world. In this competition, firms – and countries – have to restructure and focus on activities where they have strong chances to keep or obtain competitiveness. In today's economy traditional factors of production, like labour and capital, are less important than those ”competitiveness creating capabilities” which plants, firms, regions or countries may develop over time.

Conventional wisdom, strongly supported by orthodox trade theory, tells us that high cost countries like the European, have to focus on high-tech knowledge intensive activities in which they are supposed to have comparative advantages which at best compensate for their disadvantages as regards labour costs. The large differences in labour costs between mature industrial regions like Europe and ”tiger regions” like those in Asia contribute with arguments for such a conclusion.

The problem – somewhat neglected – is to identify in what knowledge intensive activities European based units can maintain competitiveness and thus contribute to employment and growth. The standard answer to that since about two decades ago is high-tech industries, i.e. those industries which reveal a high R&D intensity. We should not, however, underestimate the problems of successfully running a core competence strategy focused on high-tech industries only. First because the high-tech sectors, as normally defined, make up less than 15 percent of manufacturing industries within the OECD area and in fact approximately 10 percent within the EU. This level has been more or less the same since the mid 80ies. Due to the fact that the relative share of manufacturing is declining in all advanced industrialised countries, that leaves us with a high-tech manufacturing sector of approximately 3 percent of all economic activity within the OECD as well as within the EU. Focusing on such a small part of the economy will simply not solve any fundamental short term or mid term problems of structural change towards a knowledge based society.

Secondly we also have weak reasons to conclude that Europe's South and East Asian competitors find it relatively more difficult to obtain excellence in science based industrial activities just because they have low labour costs. In fact – and just to illustrate the argument – the growth rate of Chinese science and high-tech industries is (as we show below in the text) as fast as its growth rate within mature industries; thus challenging European economies on all fronts.

That is the context for our paper. We have within the European PILOT project (Policy and Innovation in Low-Tech) analysed innovativeness and knowledge formation in firms within so called low-tech and medium low-tech (henceforth: LMT) industries, i.e. those industries which (approximately) have a R&D intensity less than 0.9 percent or between 0.9 and 3 percent of sales respectively. Roughly these industries contribute to half of value added within manufacturing production, and the structural change taking place within them due to fierce international competition is much more important for employment and welfare for the foreseeable future than what happens in the high-tech sectors.

The aim, consequently, is to identify the conditions for knowledge formation, innovativeness and creativity – if any – taking place, or potentially taking place, in those industries being outcounted or even neglected in industry and technology policy as well as by many academic analysts. Our basic assumption is that also within mature industries recording low R&D and with unfavourable cost conditions at least some firms – or networks of firms – may develop capabilities which for a long time make them profitable and competitive. In short, it is our assumption that there is a neglected variety in these sectors. And due to the size of this sector also small innovative and high-performing segments of mature industries may contribute as much as the more high-status activities. This is also in line with recent research focusing on the innovative variety within industries (cf. e.g. Baldwin & Gellatly, 1998)

The paper is structured as follows: in section 2 we shortly present the shortcomings of the dominating conceptual reasoning which make it difficult for us to grasp and analyse innovativeness outside the so called high-tech – i.e. the R&D intensive – sectors. Section 3 contains the introduction of the concept of "innovation enabling capabilities" which we developed to overcome this shortcoming. This concept is in section 4 developed further and illustrated with evidence derived from a series of company case studies from the PILOT project. Finally, in section 5 we draw conclusions as regards policy and further analyses.

2 The limitations of our concepts and tools

There is by now a vast theoretical literature on the shortcomings of the dominant concepts developed to describe and analyse industrial and technical change on the one hand and to use these as tools for promoting policy targets as regards employment, growth and competitiveness on the other (for an overview, see Laestadius, 2005).

These shortcomings may roughly be classified into one or more of the following families of argument; arguments which, in addition, are related to – and to some degree also dependent on – each other:

- *The irrelevance of the linear model:* in short, this is the old question of the relationship between science and technology, between natural science and engineering science. The discourse between engineering science (school culture) and engineering practice (shop culture) is also related to this. In its modern variety the linear model originates in the Vannevar Bush report (1945), which not only coined the concept "basic research" but also laid the foundation for policy efforts on basic research in order to promote competitiveness, employment and growth (Stokes, 1997).

The critique against the linear model follows several paths: (a) Although all technical change by necessity has to be in line with what natural laws allow us to do, it must not necessarily be based on scientific activity or even on established scientific knowledge; (b) and even if it is based on scientific activities, it is not necessarily based on recent ones – innovations, i.e. creative combinations, from the *stock* of knowledge may be more important for our wellbeing than creating *new* scientific knowledge. This was in fact what Schumpeter (1911) already told us. (c) The relationship may, in addition, be the other way around, i.e. technology creating the foundation for scientific knowledge (cf. e.g. Kline & Rosenberg, 1986). (d) Science and technology / engineering may be relatively independent from each other (cf. e.g. Barnes & Edge, 1982; Brooks, 1994; de Solla Price, 1984; Rip, 1992). In particular it may be argued that there are many potential engineering solutions – of which some are better than others – related to the same science / knowledge base; and finally (e) non-science (and non-technology) based factors like institutions (including culture) and organisational structures (and changes) may be much more important than scientific advances. This latter argument may also include the simple fact that it is far from self evident that people in advanced countries will focus their demand on products and services that draw their immediate knowledge base from advanced science rather than from professional creativity in a broader sense.[1]

- *The rise of the service sector:* this may be a very profane way of introducing the coming of the post-industrial society into the argument. However, approximately 70 percent of economic activity in the most advanced industrialised countries now consists of services out of which significant parts are highly qualified (Wölfl, 2003). The service part of total value added increases all over the mature industrialised world. The innovation discourse, containing an innovation concept nowadays strongly related to science and R&D, has – we argue – to a large extent co-developed with hardware producing industries like manufacturing. It is far from obvious that the innovation concept inherited from manufacturing – although transformed – is the best way to capture the dynamics of the service sectors (Tether, 2004). The magnitude of this problem will increase with the rising share of services in the economy as well as with the rising share of knowledge intensive services relative to the service sector as a whole, the details of which we will return to below.

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1 This is, by the way, an old argument with roots in the discourse on post-materialism (cf. Inglehart, 1977) and post-industrialism (e.g. Bell, 1973/76) .

The rise of the service sector is in itself a complex phenomenon containing relocation of traditional service activities (although maybe modernised) from manufacturing sectors to service sectors (like outsourcing of cleaning and computer services) as well as the growth of traditional service sectors (like restaurants and lawyers) and the emergence of new service sectors (like mobile service providers). In addition the activities within manufacturing firms may become more indirect (i.e. service like). Manufacturers may as well transform their business concept towards more of integrated solutions, i.e. offer function or performance instead of selling hardware products (cf. Davies in Prencipe et al, 2003). Or they may – as in the case of contract manufacturing or industrial operator models (cf. Bromberg, 2004) – even sell manufacturing itself as a service. In short: in most of these cases there is an element of customisation connected to the service activity challenging the traditional innovation concept.

- *The new production of knowledge:* there seems to be a general agreement among analysts that the character of knowledge production (or knowledge formation) is changing and has been so during recent decades. This is a transformation in many dimensions of which at least the following seem to be of interest in this case: (a) The Gibbons et al (1994) argument that the increased specialisation of academic knowledge formation necessitates more of integrative skills and synthesising competencies (which probably fall outside what we normally identify as science); there are many possible conclusions following from the Gibbons et al position but they may be analysed in another context.[2] (b) Due to organisational change, higher educational levels and decline of traditional manufacturing activities a larger share of employees get opportunities – as well as demand – to work with their brains rather than their hands. In short: activities aiming at innovations are not necessarily discriminated from normal ”production” in what we label knowledge based firms. This is probably most evident in those firms labelled Knowledge Intensive Business Services (KIBS); but also in manufacturing is creative problem solving for clients increasingly a normal activity and a means to create competitiveness (cf. e.g. Davies in Prencipe et al, 2003). Although advanced this is not innovation proper, neither is it R&D or science (although there may be a scientific foundation for the knowledge base); still less is it standardised routine work. In fact qualified and situation specific application of professional skills fall outside the innovation concept as we normally use it. It may be argued that the modern discourse on knowledge management includes this aspect (cf. e.g. several papers in Nonaka & Teece, 2001), but its problematic relation to the innovation concept is not made explicit.

- *The conventional wisdom on the characteristics of complexity.* The traditional division of labour between industrialised and less industrialised countries as well as the historical processes of industrialisation may have contributed to a neglect on what constitutes complexity in industrial and technical activity and knowledge formation. Assuming that those firms and countries that can manage complex processes show competitive advantages the characteristics of complexity becomes a core issue. In short: when colonial heritages are thrown away and the fetters of hierarchical struc-

2 It may be argued that what Gibbons et al (1994) have noticed has to a large extent been there all the time in scientific practice (Rip, 1997; Weingart, 1997 and several papers in Bender, 2000) and particularly in traditional engineering.

tures are loosened what makes us assume that the catching up countries will face competitive disadvantages in science based activities rather than in traditional engineering and crafts? This argument may be illustrated by a simple empirical analogy: the recent (i.e. last ten years) advancement of Chinese science, according to many indicators, is much faster than is the case of the Chinese economy as a whole. Just to illustrate: the growth rate of international citations of Chinese scientific papers published in English has been 16 percent annually during the decade 1995-2004 moving Chinese citations to the same level as English growing with approx. 2.3 percent annually (ISI, 2005-02-27). Although the details of this need a paper of its own it may be looked upon as a stylised fact indicating that latecomers may catch up starting in the assumed most complex end as well; and that is challenging for conventional wisdom.

- *The network character of the economy:* Although globalisation is far from new, and advanced global production processes have been organised for almost half a century by now, we may follow Castells (2000) in arguing that the network character of the world economy has dramatically increased during recent years influencing also innovation processes as well as our means to understand them: if value is added in a configuration of distributed actors rather than within a single organisation ”the unit of reference is no longer the firm, the research centre or the consumer. It is the system of co-ordinated links that exist between these different actors” (Bell & Callon, 1994:67). Then it is much more difficult to identify the relative importance of the different parts of the network as regards innovativeness: synergies may be created from the links between low-tech units and high-tech units in an economy. The importance of this argument should not be underestimated. The capabilities to identify and creatively combine relevant distributed assets (knowledge and others) may be the key to innovativeness, and ”low-tech” firms may be the nexus through which a lot of advanced competencies are integrated or synthesised.

Summing up we cannot expect to find strong and reliable connections between localised scientific advances – or R&D-advances – on the one hand and growth of employment, production or competitiveness in the same locality on the other. Innovation surveys – of which several are performed within the EU – face problems although they use more elaborated innovation concepts intending to handle at least some of the limitations discussed above. In short: there are lot of ”innovation paradoxes” within the EU.

3 Capabilities and non-science based innovativeness

One difference between economists and other social scientists is that the former, due to their research interests, tend to underestimate differences between firms (cf. Nelson, 1991). Firms differ and they do it due to internal mechanisms – not only as a consequence of the competitive conditions in which they are embedded (cf. Porter, 1980). This difference between firms was present already in the original writings of Schumpeter (1911), it was revealed in important studies in both industrial and organisational sociology (among others Woodward, 1965 and 1970, Burns & Stalker, 1961) and economics (Chandler, 1966, Cyert & March, 1963, and Penrose, 1959). Since about two decades this has developed into a discourse on ”the resource based theory of the firm”; in its later varieties developed into a ”dynamic capabilities approach”.

Firm differences is a core point in evolutionary economic theory (cf. Nelson & Winter, 1982). Much of the recent research in this area originates in contributions by Kogut & Zander (1992) and by Teece & Pisano (1994). The core results in this discourse is that these differences may be analysed in terms of capabilities orchestrating and mobilising resources available for firms as regards knowledge formation and productive activities (e.g. Dosi, Teece & Chytry, 1998; Foss & Robertson, 2000; Dosi, Nelson & Winter, 2000; Zollo & Winter, 2002). The capabilities of one firm cannot instantly be transferred to another. Transferring capabilities has transaction costs. Capabilities are characterised by complexity having developed through learning processes, which may contain elements of tacitness. The cumulative character of these learning processes contribute to path dependence, i.e. firms tend to follow certain trajectories in their development.

Though the discussion on capabilities has developed alongside the debate on the emerging knowledge society or knowledge-based economy it is easy to connect the two discourses. Because it is quite obvious that the most critical point in the knowledge society is not knowledge as such but knowing and in particular the capability to cope with different forms (codified, embodied, tacit etc) of recurrent new knowledge.

Now it may be argued that if these capabilities are potentially significant in magnitude – and if their transferability is limited in the short run – compared to, say, the costs of labour and standard machinery, the result of the competitive struggle between firms facing different competitive environments is far from evident. In short, the potential of the dynamic processes may be more important than ordinary factor cost differences. There is thus a window of opportunity also for innovative and creative firms in mature industries in high cost countries to compete on the world market.

The coupling of innovation to capability rather than to R&D opens for a much wider understanding of innovativeness and knowledge formation processes than what has normally been the case (although there are tendencies in that direction in the present reformulation of the Oslo Manual). There are of course many firms which develop significant parts or even most of their capabilities in the R&D department. With our approach, however, the relative importance of the R&D units becomes an empirical question rather than something postulated or assumed a priori. This is fully in line with ideas already proposed by Kline & Rosenberg (1986) and by Faulkner (1994). It is also fully in line with much of the recent discourse in knowledge management (e.g. Nonaka & Teece, 2001 the papers of which include further references).

Capabilities are created in organisational units and structures on all levels. Although our primary unit of analysis in this paper is the firm, we may imagine that capabilities are created in individual plants, in departments and sections of plants, as well as in various networks, alliances etc. It may be argued that the capability concept, as it is introduced here, does not significantly deviate from the ”innovativeness” which may be derived from the original Schumpeterian innovation concept from 1911. For Schumpeter innovations were those creative combinations which made firms take off from their road towards equilibrium, which made them capable of establishing temporary monopolies; i.e. creating what we usually label situations of monopolistic competition where the competitive struggle not necessarily is fought with prices but with better performance, higher qualities etc. This innovative behaviour is (following Schumpeter) explicitly not restricted to technology, and still less to science labs.[3]

The fact that innovations over time so strongly have become associated with technology is one reason for our adoption of the capability approach: as we have argued above, firms do not necessarily need advanced technology to become profitable. Another reason is the strong connection which has developed between innovations and new knowledge – and primarily "new to the world". The capability approach opens for the fact that it is not necessarily the uniqueness which matters but the variety created by difficulties to imitate or to follow the paths tread upon by the leading performers (and by the variety of preferences on the demand side). The successful knowledge based service firm may be successful not because it is innovative in the conventional connotation of the term, but due to the fact that their staff have learned the professional skills and have developed a capability to perform better – at least from some aspects – than their competitors as regards customisation of professional routines. In short: the capability approach leaves us with a much wider concept for understanding the performance of firms which do not reveal high records in R&D or innovations as we normally define them.

Going further in our analysis we may develop the capability concept somewhat. Dosi, Nelson & Winter (2000:3) argue "the term 'capabilities' floats in the literature like an iceberg in the Arctic sea … not easily recognized as different from several icebergs nearby"; neither is it in itself unambiguously distinctive. This can be illustrated by two recent, and prominent, definitions of the term. For Teece at al (2000:339) "dynamic capabilities are the *ability to reconfigure*, redirect, transform, and appropriately shape and integrate existing core competences with external resources and ... assets to meet the challenges of a time-pressured, rapidly changing Schumpeterian world of competition and innovation". Whereas Zollo & Winter (2002) suggest the alternative definition "a dynamic capability is a learned and stable *pattern of collective activity* through which the organization systematically generates and modifies its operation routines in pursuit of improved effectiveness" (italics in both quotations added). For our purpose here the more abstract understanding advocated by Teece and his colleagues seems to be more appropriate. That is to say, we understand capabilities not as a pattern of activities but rather use the term to address specific preconditions for specific activities: a particular configuration of enabling cognitive, financial and material (machinery

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[3] So far we may support our arguments with some illustrative examples. The Swedish firms Ikea and Hennes & Mauritz (H&M) have during the 1990ies established themselves as fast growing firms on a global scale. None of them has any R&D worth to mention, neither are they known as world leaders in what we traditionally identify as high-tech (cf. e.g. HM, 2004). Leaving their successful market strategies aside for a moment – assuming that these strategies basically mirror their underlying capabilities – we may identify that these firms have excellence in design and logistics. Going deeper into that we may argue that the design competencies of these firms include excellence in design for the use of the products as well as design for production, manufacturing, assembly, transport etc (and with "use" we – of course – include the aesthetic qualities and cultural values connected to the product, not only a narrow "function" perspective). This is probably most obvious with Ikea where the customers are fully integrated into the process of storage handling, transport and final assembly of the products.

etc.) resources which characterises an organisation and which constitutes potentiality for this organisation.

Following Dosi et al (2000) we save that concept for a fairly large scale unit of analysis containing intentionality and conscious decision making as well as routines as building blocs. Capability is related to a recognisable purpose expressed in terms of significant outcomes it is supposed to enable. This also means that capability building can be a strategic aim (cf. Tidd, Bessant & Pavitt, 2001) whereat both the actual process of capability building and the definition of specific aims is affected by the capabilities already present at any point in time. The latter direction of impact has been labelled with the term absorptive capacity or absorptive capabilities (Cohen & Levinthal, 1990; Laestadius, 1995). Here we are particularly interested in the dialectical move between outcomes and preconditions.

We may identify two analytical dimensions[4] of "innovation enabling capabilities" which are tightly interwoven empirically.

- *Transformative capabilities* constitute enduring ability to transform available general knowledge and competence into plant, firm or task specific knowledge and competence. This is a core competence particularly in LMT industries: the general knowledge on traditional industrial techniques like welding etc. is spread all over the world. The ability to transform it into specialised and economically competitive "high class zero defect" competence separates the profitable firms from the rest.

One may describe the underlying processes as a shift between levels which has to be mastered by an organisation: globally available knowledge is being accommodated and transformed locally for local use. Thus we may link our reasoning to a long-standing discussion in STS – science & technology studies (cf. Jasanoff et al, 1995 for an overview). Rip (1997) for instance provides a convincing elaboration of the relevance of this distinction. He argues 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 as regards the claimed validity – universality in the one case vs. adequacy in the other (cf. also Disco & van der Meulen, 1998). And they differ in form as well. Global knowledge is always codified as it refers to a paradigm[5] whereas local knowledge, though having codified elements (instruction handbooks, formal organisational rules, technical process protocol etc.), is characterised by some degree of tacitness.

This difference has considerable practical consequences. The change from the global level to the local is not just a transposition of the same but always implies transformations. The phrase "application of generally available knowledge" (i.e. global knowl-

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4 This bears some resemblance to Teece et al's (2000:345) discussion of transformation and reconfiguration as part of a firm's organisational and managerial process aiming "to reconfigure the firm's asset structure, and to accomplish the necessary internal and external transformation". But they focus on transformation and reconfiguration of a firm's capabilities. With our concept we want to underline that the adoption of e.g. distributed knowledge may entail not only transformations (and re/configuration) on the side of the adopting organisation but also of the adopted knowledge.

5 This is what makes global knowledge – different from local knowledge – easily transferable in principle; global knowledge is by definition mobile.

edge) tend to shroud both the complex processes of transformation and adaptation and their individual and organisational preconditions. The ability to render global, e.g. technological knowledge useful in and for specific local circumstances *always* presupposes not only professional “literacy” as for the respective technological discipline but also contextual experience and practical knowledge – that is, knowledge and know-how concerning the local (cultural, technological, financial, etc) possibilities and needs.[6] This competence is fundamental for an organisation’s transformative capabilities.

Transformation of global knowledge in local settings proceeds as contextualisation, that is, the global knowledge is not simply replicated locally (cf. Zollo & Winter, 2002) but it has to be translated according to local conditions which may include both (re-) codification and practical adoption “by using”.[7] And this in turn may necessitate transforming and orchestrating of competencies and resources available in the firms capital – human as well as material.

- *Configurational capabilities* constitute enduring ability to synthesise novelty by creating new configurations of knowledge, artefacts and actors. There are at least three aspects of configurational capabilities.

(a) For once, integrating over dispersed knowledge bases and areas: Success in innovation is in principle to a large extent based on the “*synthesising competence*” (Bender, 2005) of actors, that is, on their ability to tap distributed knowledge and know-how from totally different areas and to recombine them creatively. This may include knowledge embodied in hard- and software, it may be scientific knowledge, design competence, or expertise in logistics, it may be codified knowledge or tacit knowledge incorporated in individuals or teams. This may also include mixes of science based knowledge with tacitness and crafts as well as mixing different scientific disciplines as is discussed in Gibbons et al (1994).

Although most of the technologies used in industry are well known in general as well as in most of their details since years or decades – what counts is often the precision and speed of a new architecture perhaps only marginally different from another one. This may be illustrated from pulp & paper industry where since long well known different technologies are integrated into large scale systems (Laestadius, 1998b). This configuration out of different technologies or systems – although by definition unique in its important details – may normally be too small in technological terms to be identified as ”innovation”. For those who master the system, however, these details may constitute the difference between high profitability and average performance. It may be argued that to a large extent this synthesising activity across different technologies

6 This is why an attempt would not make very much sense to characterise LMT industries as being dominated by practical knowledge as opposed to high-tech industries which are allegedly dominated by codified knowledge. The latter might be a useful starting point for a description of Science as a specifically organized societal system; but not to explain acts of doing science, that is research, and even less so to explain industrial R&D processes. To contrast practices of innovation in LMT companies with such a stylised picture of Science would be similar to an attempt to compare apples and oranges (strictly speaking apples and a particular picture of oranges).

7 Cf. for instance the analysis by Collins (1985) on replication of scientific practice.

and knowledge fields is what qualified engineering is about.[8] We may here identify a dichotomy between analytical competence on the one hand – that is, being able to identify technological concepts or equipment that are potentially relevant to one's own business – and synthetic competence – being able to transform and rearrange them creatively – on the other (cf. Laestadius, 1998b).

(b) The other dimension of configurational capabilities – empirically tightly interwoven with the first – is an *organisational* one: the enduring ability not only to combine pieces of knowledge and technology but also to link actors together who posses relevant knowledge, technology and competence. That is, configurational capabilities include an organisation's aptitude to efficiently provide for access to and use of distributed sources of relevant knowledge and competence; this may in many cases involve the ability to cooperate with external R&D facilities or design labs. And it also embraces an organisation's competence to timely and flexibly manage logistics.

(c) The third dimension of configurational capabilities is *design*. The design discourse spans over a wide domain including narrow as well as broad interpretations of concepts like function and form and their interrelationships. It also spans over professions from artists to engineers and over activities from styling to the configuration of complex systems. There is, for the purpose of our research, no need to analyse this design discourse in depth (for introductory texts cf. Alexander, 1964; Julien, 2000; Simon, 1996). Of importance is that the act of creation performed by designers and by engineers to a large extent belong to the same realm. The aim of their activities is the creation of a new physical order, or organisation – what Alexander (1964) labels form – in response to function. The basic idea, thus, is to achieve fitness between two entities: the form and its context (e.g. between the car and the consumers or traffic regulation authorities). This act of creativity, i.e. configuring and modifying artefacts to meet certain needs and expectations, has of course no necessary relation to recent scientific advances and is an important activity all over the innovation process (cf. Kline & Rosenberg, 1986). In fact it is, again, very close to what we may include in the original Schumpeterian (1911) innovation concept although we have no indications that Schumpeter himself was aware of that aspect.

The basic reason for including design as a discrete analytical dimension of configurational capability is simple: it seems that the variety of the design concept can be captured within the notion of configuration, thus eliminating problems of drawing strong analytical borders between design, engineering, logistics etc.

Our notion configurational capabilities has family resemblance with "combinative capability" introduced by Kogut & Zander (1992) which they explain as generating new applications from existing knowledge.[9] It is also wholly in line with the funda-

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8 This also provides an engineering perspective on the mode 2 concept developed by Gibbons et al (1994). Engineers have for a long time developed their industrial innovations – whether product or process related – across the disciplines of natural sciences and parts of engineering sciences as well. It may be the case that the scientific division of labour has increased the specialisation of disciplines – although Gibbons et al do not provide much empirical evidence on this – but the mode 2 phenomenon as such is far from new on the planet, neither is its consequences for engineering.

9 This is very close to what innovative entrepreneurs do in Schumpeter (1911).

mental STS argument that new technology and innovation always entail a change in networks of social relations. There is a variety of concepts that address this co-evolutionary process: Hughes (1986) analysed the development of power supply systems in a "seamless web" of technology and political and economic institutions. Callon (1986) argued that the stability of technological solutions is dependant on the successful networking of human and non-human elements, a process Law (1987) called "heterogeneous engineering". Bender (1999) analysed technology development as a process of aligning actors, artefacts, interests and technological concepts that brings new "socio-technical configurations" into the world. All these studies document that innovation is not merely a scientific or technological process with economic consequences (and presuppositions) but normally implies changes of "heterogeneous" configurations and social relations.

We may conclude the discussion for the present with a pointed reformulation of the basic practical problem for innovators: The major task is not necessarily to develop and/or apply latest technological knowledge but innovation always entails the creation and management of sustainable new configurations of various types of knowledge, actors and artefacts. And an organisational precondition of this is the creation and reproduction of appropriate innovation enabling capabilities in the sense just explicated.

From this vantage point the problems described by Henderson & Clark (1990) turn out to be not specific for a certain type of innovation, architectural innovation. They show how certain ways of doing things tend to crystallise into organisational structures, information filters, and communication channels which, on the whole, shape an organisation's capabilities. They also highlight the problems incumbent firms face when they are confronted with architectural innovations. We argue that what they describe as a specific threat in this specific situation is not so specific at all when you take into account that innovation is always about reconfiguring existing knowledge, components and actors.

In the next section we try to identify innovation enabling capabilities of LMT firms via a specification of the demands such firms have to meet to be successful. In so doing we focus on the two dimensions elaborated above: *transformative* capabilities – being able to transform globally available knowledge into local knowledge and competence – and *configurational* capabilities – being able to configure (a) dispersed knowledge and know-how, (b) actors and other "repositories" of knowledge and know-how, and (c) functional features and solutions (design). The discussions draws on company case studies conducted within the PILOT project.

4 Experiences from the PILOT project – innovation enabling capabilities of low-tech firms

The question how technical innovations are initiated and managed in firms with no or only little engagement in scientific research and whether there is a low-tech specific mode of innovation is one of the issues the PILOT project teams investigated in a series of company case studies. In principle the work focused on both process and product innovations though the main emphasis was on the latter. The distinction used in the project was a rather pragmatic one. We conceptualised the development and launch of an item new to its producer as a product innovation and as process innovations those changes in the production process (in a wide sense including e.g. design and logistics) which representatives of a company described as innovative.

This is admittedly very pragmatic. Simonetti et al (1995), for instance, introduced a far more elaborated conceptualisation. Slightly simplifying one may say that they establish the difference mainly with recourse to the location where an innovation has its first effects. When it is the producer it ought to be taken as process innovation and if the first users are clients or another sector than the one where the novelty was created it is a product innovation (l.c.: 79-82). Their methodological argument is that the character of an innovation can only be determined when you survey both sides. As this part of the case study research in the PILOT project focussed primarily on the conditions relevant for single low-tech producers we usually abstained from this.

It may, however, be argued that with our capability approach we do no necessarily have to discriminate between product and process innovations. In addition, in systemic industries like pulp & paper or steel processing the distinction between product and process innovation is difficult to define, new forms often co-develop. In fact that may also be the case within individual firms which perform radical design innovations transforming more or less the whole business concept. The design solutions of Swedish IKEA may illustrate this: they incorporate all aspects of products and processes. What counts, in short, is simply the creation of variety, the differentiation, sometimes on the margin, which makes some firms profitable and others not.

Forty-five case studies in eleven European countries have been conducted. More than half of the firms belong to the metal working sector[10] the rest is distributed over selected other industries.[11] The selection of companies was not a representative sample nor did we select firms because they show excellence and profitability far above the average. To qualify as a PILOT case a company had to be *innovative* (regarding products and / or processes), economically *successful* and of a critical *minimum size* (about fifty employees or more). And because innovation in low-tech has not been investigated very well so far, the case studies' purpose within the overall project was rather to state problems more precisely than to answer questions (see Schmierl & Kämpf, 2004 for a general overview).

For the inquiry we used a standardised questionnaire to collect basic data on the respective company, its production process and its relations to suppliers, clients and, if so, partners. This research instrument was complemented by about half a dozen semi-structured extensive interviews for each case study with company representatives on different levels and with different functions (based on a master guideline common for all national project teams), by site inspections and by an analysis of publicly available

10 NACE DJ.28: Manufacture of fabricated metal products, except machinery and equipment.

11 Principally food, beverages & tobacco (NACE Subsection DA), textiles, apparels & leather (Subsections DB and DC), wood products (Subsection DD), paper, pulp products & printing (DE) or furniture (DN.36).

documents of the firms (catalogues, product specifications, internet presence, self-portrayals etc.).

Our intention was to find examples to illustrate specific aspects of innovation enabling capabilities of LMT companies, that is, cognitive, organizational and material abilities a non-research-intensive firm has to develop to be able to generate profitable innovations.

(i) Transformative capabilities: structural ability to transform globally available knowledge into local competitive advantages

With respect to transformative capabilities we have argued above that high performance in innovation does not necessarily imply creation or use of latest scientific insights but rather the ability to identify and take up potentially relevant knowledge and translate it according to the local conditions a firm is confronted with. This may or may not include latest scientific and technological knowledge; but in LMT industries we can assume that this will – almost by definition – not be the main "raw material" for successful innovations. A few examples from our case studies can illustrate this point.

Krämer, one of the companies in our sample is a German producer of large (with up to more than four metres diameter) longitudinally welded steel pipes used mainly in the construction industry (for high-rises, offshore drilling platforms etc) or for pipelines. A major problem for the transportation of aggressive fluids or gases in pipelines is that the tubes are subject to rigorous and sometimes conflictive demands. They must be highly resistant to detrimental chemical effects of the conveyed substance and at the same time very robust to endure physical impacts such as extreme heat or high pressure e.g. in the deep sea. The technical difficulty is that steel qualities that provide good protection against corrosion are usually susceptible to fatigue and vice versa. The solution to this problem are so called clad tubes the outer shell of which is made of a very hard, pressure resistant steel while stainless steel and alloys based on nickel are used for the interior of the tube, that is, material which is dimensionally less stable but unsusceptible to corrosion. Such pipes combine high strength with distinct surface properties in a single product. The principle of this "coated tube" is well known, but the principle alone is not a usable solution. Different pipes have to be designed for different applications and the most delicate point in terms of knowledge and know-how is the welding of the respective compound material.

That is to say, innovation in this field does not mean to develop fundamentally new products or principles but to develop particular artefacts and manufacturing procedures. "A clad tube" is nothing new. "The clad tube" for a specific client very often is. And to design and produce it requires much more than just local replication of ready-made, globally available knowledge. In the words of the company's managing director: "You really have to develop such a product from the beginning to the end. And you have to test every single value and document it. We've got at least six bulky folders here where each development step and all the test results are recorded. To develop such a product can last up to two years and may cost a hundred-thousand Euro." Neither this money nor the time is accounted as R&D expenditure and the work involved is not laboratory work in the usual sense. The novel products are developed by small teams of engineers and technicians besides their everyday jobs in the plant. If needed the teams get in contact with externals partners; among them are scientific institutes.

This firm is without any doubt innovative and it has to be because otherwise they would not stay in business much longer; they are too small to compete with the very large producers of standard pipes. Instead, they serve niche markets and innovation is their core business. But the company's innovativeness is in no way determined by excellence in R&D in the orthodox understanding. Instead, what gives them a competitive edge are the capabilities to adopt and transform what is well known in principle into solutions for particular needs.

Transformation of relevant knowledge in the sense brought forward here is not limited to expertise stored in books, databases or brains but may include technical equipment. In the late 1980es the same company bought a huge plate press which was used in a shipyard heretofore. With this machine an enormous heavy sword hit a steel plate which was moved laterally in defined intervals and in so doing it curved flanks of ships. The purchase of this machine was not just an "import" of ready-made equipment from the shipbuilding industry to tube manufacturing. The buyer had to re-construct it. In cooperation with an engineering company they developed a control programme to meet the very much tighter tolerances characteristic for their business, and this software also adds flexibility – a critical factor for a supplier of niche markets – because it allows for processing tubes of very different size in best time. The whole system was tested, modified and re-tested. The staff developed skills and routines in using the new equipment. And not only in manufacturing did it make a difference, it also opened new possibilities for the design of tubes.[12] In fact, the tube company absorbed machinery and know-how developed, approved and used elsewhere and transformed and recombined it according to their (and their clients') specific needs and possibilities. This resulted in innovative technical equipment and novel process technologies that enable the firm to meet new demands and to design and manufacture new products.

Also *Finnscrew*, a world leading provider of propulsion systems for ships with high manoeuvrability demands (such as ice breakers), may be mentioned in this context. The proficiency of this firm is based on accumulated experience in propeller design as well as casting and grinding techniques. The design competency, in its turn, is based on acquisition and creative transformation of available technology which the firm has learned to master and to integrate with academic knowledge in hydromechanics acquired through collaboration with technical research institutions in Finland. Thus they took up and translated globally available technologies, the casting and grinding competence to meet the highly specialised needs of propeller manufacturing. That includes the metallurgical composition of the castings as well as the processing and quality checks. All this know-how can hardly be protected with patents; competitors may be able to imitate – but to do so they have to build up the appropriate capabilities; that is to say, they cannot reach Finnscrew's excellence without cost.

[12] With the traditional bending roll machines it is not feasible to machine thick walled tubes longer than four meters.

The transformative capabilities of two Swedish located firms show in a quite similar way: *Bahco Tools*, a producer of hand tools and *Ostnor AB*, manufacturer of sanitary armature. Both firms draw their knowledge base from mature technologies like forging (Bahco) and casting (Ostnor). But they have developed internal capacities to transform these general technologies – global knowledge – into high-end quality including design work.

The Irish *BCD Engineering* illustrates another aspect of transformative capabilities and of their commercial relevance. The company designs, installs and validates stainless steel process systems and manufactures atmospheric pressure rated vessels to applicable design codes (see *iv* below for more details). One recent innovation project of the firm is Cleaning in Place (CIP). Cleaning in Place means that once a product has been processed through any particular piece of machinery, that apparatus has to be cleaned before either a different product or another batch of the same product is processed so that no cross contamination can occur. The most effective way to implement CIP technology is to design it into a process. This involves the addition of spray systems, tank cleaners, nozzles, and seals in order to automate the cleaning process. CIP technology was always relatively extensively used in the dairy industry and now the volume of its use is increasing dramatically in the pharmaceutical industry. In this industry, particularly with the growing trends towards non-chemical related drugs and more pharmaceutical and biopharmaceutical, even biotechnological ingredients, as you move up that scale the requirements for cleanability and sterility matters. Therefore cleaning processes are extremely critical and BCD identified such technologies as something that clients are willing to pay for. They already had significant experience of CIP from the food industry and were able to develop it further to meet the requirements of applications in the pharmaceutical industry. One key to the firm's success seems to be this dynamic character of its proficiency; they are not only a competitive designer and producer of vessels and process systems but they also have capabilities to transform expertise in one field into knowledge adjusted to requirements and conditions in another environment, that is, they possess capabilities to redesign and creatively reproduce their own knowledge bases.

All of the cases outlined here support two main arguments brought forward in much of the literature discussed above: New technological knowledge does not necessarily emerge from R&D in the usual sense. And elaborated new technological knowledge is not always a precondition for technical innovation. Instead new knowledge and novel technologies may be the result of creative use of well established knowledge which usually implies its transformation – and its (re)configuration.

Configurational capabilities

To be successful an LMT company must develop capabilities to creatively combine distributed knowledge (which may include its prior transformation). The cognitive side of this (know-what) is to some extent congruent with what Cohen & Levinthal (1990) addressed with the term absorptive capacity: the ability to evaluate and utilise outside knowledge. But it has also an organisational side and that is the ability to identify actors and other "repositories" of potentially relevant knowledge (know-where) and to organise some kind of cooperation or interchange with them. In fact one could talk about a double-helix of know-what and know-where. That is to say, what we label configurational capabilities is an important aspect of an organisation's proficiency in networking or in other forms of trans-organisational interaction.

(ii) (Re-)configure dispersed/distributed knowledge

We have seen many examples of creative configuring of distributed knowledge and competence in the case studies. One of them is *Voestalpine*, an Austrian producer of rails. Their capabilities to join forces with external expertise in order to foster development of innovative product solutions are a critical success factor. It is important to note that we are not talking about just the competence to organise external support for continuous improvements of their core products. This is something one can fairly expect from any competitive producer. The competitive edge results from the ability to be more creative when needed. In this specific case the company is confronted with a general trend in the railway industries. Due in part to structural changes on the side of many railway transportation companies (liberalisation, segmentation into independent functional units etc) the customers tend to ask for system solutions rather than simply for tracks. In such a situation suppliers have to be able to functionally augment their core products without giving up the advantages of specialisation. The firm discussed here is well known for being able to produce the worldwide longest head hardened non-welded pieces of rail (120 metres). This is in itself an innovation. But they also offer a novel process to lay these bulky pieces. The appropriate handling system was developed in collaboration with a German manufacturer of railway equipment and machinery; its design embodies the merged expertise of both partners.[13]

The combination of (formerly) distributed knowledge and competence did in this case take the form of a joint product of independent partners. The tube manufacturer *Krämer*, already introduced, provides quite another example for what we suggest to call configuring distributed knowledge. To enhance product qualities some tubes have to be heated up to more than 1,000 Centigrade after welding and straightening. If you do this using an oven or any other kind of external heat supply it is very likely that the heavy tubes will deform and in the worst case they simply collapse because the heating softens the steel. To prevent this, engineers of the firm implemented an innovative annealing process applying electromagnetic induction which allows for extremely high temperatures without making any alterations in the dimensional tolerances of the pipes necessary. Neither the idea nor the general process was something completely new heretofore. It was even used for tubes before, if just for much smaller ones. But this firm constructed, in collaboration with an engineering consultant, the machinery to accommodate this "in principle available technology" to their products and local needs. Which implied much more than simple upscaling in size. As a matter of fact, they creatively configured fundamental knowledge on physical principles, experiences made elsewhere with technical solutions based on these principles and own expertise in handling huge steel tubes. And thus they synthesised a new technological system

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13 The Austrian "rail smithy" holds the exclusive sales rights globally for this device produced by the German partner. For the Austrians that means not only diversification of there product range, the availability of the dedicated handling system does also support marketing of their innovative ultra-long rails.

and related new knowledge. The novelty results from the ingenious combination of more or less well-known technological and cognitive “components”.

The two metal working companies *Killala Precision Components* (KPC) of Ireland and the Norwegian *Bryne Mekanikk Serigstad* (BMS) are specialised in utilising mature standard technologies in turning, using CNC lathes and machining equipment. They produce high precision, often customised, although chiefly simple components primarily in small batches. It may be argued that they just apply generally available knowledge and technologies. But here too a closer look uncovers manifold processes of transforming and configuring knowledge. Key to success are their set of skills in problem solving, tooling, system solutions, CNC programming and to be flexible in all that and to deliver just in time. All this both requires and entails learning processes and other forms of knowledge production rather than just making use of an established knowledge repertoire. The mode of developing and maintaining the relatively close capabilities show similarities as well as differences between the two firms: KPC seems to have more of its competence in the engineering staff and BMS among the shop floor workers. None of them is fully automated although both firms also have installed the most advanced equipment. The small batch character of their production and the demands on flexibility have been the basic reasons for still using older generations of technology.

Capabilities to configure distributed knowledge may also have a temporal dimension: the ability to anticipate future customer needs. The importance can be illustrated by the experience of a Spanish manufacturer of rails, *Felguera*. As engineers of this company are in permanent contact with colleagues in their main customer’s quality and purchase department they are fairly well able to foresee what these may need even before they have expressed their requirements. This shows that frequent conversation and acquaintance with local knowledge and conditions on the side of partners (downstream the value added chain as in this particular case but also upstream) may be a constituent of innovation enabling capabilities. We are aware that there are many examples for the opposite in the literature. One may draw the conclusion that whether familiarity leads to lock-ins or to innovation can in itself depend on the innovation enabling capabilities of the actors involved of which familiarity with the use-context is but one element.

Nevertheless would we argue that knowledge on the context of application of one’s products and the ability to integrate this with “domestic” technological expertise is an important aspect of innovation enabling capabilities in general. Though it is basically impossible that a supplier knows everything they need to know in advance to keep their customers satisfied, the better they know the context of application the quicker can they design appropriate new products or prototypes. This is particularly true when the supplier produces components for larger systems. In most of the respective companies in our sample firm representatives experience it as a serious deficit that they often know only the interface between the customer’s system and the own subsystem. This is perhaps a rather mundane problem but the consequences are far from trivial. Some of the firms in our sample invest considerable sums besides the everyday business to accumulate such knowledge mainly by sending personnel to appropriate courses;[14] others would like to but cannot afford it.

The capabilities of successful pulp & paper plants (and firms) are also to a large extent related to the synthesising of knowledge from different disciplines and knowledge bases as well as from widely dispersed knowledge sources. In addition, due to the enormous capital costs involved, there are strong path dependencies in the formation and reproduction of capabilities (cf. Teece & Pisano, 1994). As analysed by Laestadius (1998a & 1998b) the relevance of the science and technology indicators is very low for the pulp and paper industry and so is also the relevance of the conventional wisdom on innovations. Behind the very low aggregate R&D intensity in the industry (approximately 0.3 percent of turnover) there is a significant variety between countries and firms indicating different paths to develop capabilities. The basic argument, however, is the systemic character of the industry and its scale. All competitive pulp & paper plants in the world are large scale complex systems fine tuned for the production of a small segment (niche) of products. And the complexity of the product basically consists of the engineering solutions on how to fit certain intended product specifications with a high speed production system.

The capabilities of our case company *Hallsta* Paper Mill is no exception. In short, the capabilities of a pulp & paper plant like theirs, specialised in thermo-mechanical pulp (TMP) based paper qualities, can be located to the acquisition, instalment and purchasing phase on the one hand and to the routines developed to run the whole system on the other. The instalment of a new “PM 11” paper machine at Hallsta was based on a set of corporate and mill strategies on what paths to follow and how to draw on the existing capabilities of the mill. The decision to focus on improved uncoated paper, useful for four colour printed catalogues, may be looked upon as an upgrading strategy compared to standard newsprint and competes with traditional high-end MWC/LWC and super calendered qualities.[15] In short the strategy may be explained as using simpler pulping technology (TMP), where they have developed excellence, and avoiding the complexity with coating and upgrading to a higher quality and price level thus challenging the incumbents in the medium quality segments. The acquisition of PM 11 was a highly qualified engineering exercise aiming to synthesise state of the art knowledge from a wide variety of knowledge fields related to TMP based paper manufacturing. Nothing of this was new to the world, most of the technologies

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14 Individual knowledge acquired thus is no capability of the organisation yet. But this way of incorporating knowledge about the application environment can be a means to build up innovation enabling capabilities.

15 A few explanations as regards technology may be necessary: there are two families of pulping technologies to feed the paper machines; chemical processes and thermo mechanical processes (TMP); the former normally supposed to be more complex. A plant having sunk costs and capabilities within one of these technologies have strong incentives to stick to the path already thread upon. The different pulp properties and qualities create certain unique niches in the paper production. However there are segments where the qualities compete and may compete in the future. Except for using different qualities of pulp (or mixing them) manufacturers of printing papers may use fillers and/or coat the papers. In addition they may calender the paper in several ways to obtain good printability. Paper plants normally strive to develop/acquire totally integrated paper machines where they can feed the pulp in the one end and spread it out on a wire, reduce the water with pressing and drying methods and finally calender it in the other – all done in high speed.

installed were in use somewhere else although in somewhat different applications. It is far from easy to identify any obvious innovations in this; unless the whole installed system is classified as an innovation. It is, however possible to identify a set of engineering solutions many of which intend to simplify the complexity of traditional solutions. A lot of engineering has also been devoted to downscale the size of the paper machine to fit the available space at the site and still maintain speed and productivity. All in all these activities are of a synthesising character, configuring knowledge from different fields of engineering and knowledge distributed among many different actors (cf. Laestadius, 2002; Bender, 2005). There are consultants specialised in supporting these activities; in the end, however, all plants have to fall back on plant specific capabilities. In the installation – at best – the accumulated knowledge of the plant is embodied (cf. Rosenberg, 1982) thus providing the foundations for the running of the new system. The detailed specifications of the system under intensive discussions with the supplying firms is a real test case on the capabilities of the plant staff.

(iii) (Re-)configure actors and other "repositories" of knowledge and know-how

Configuring distributed knowledge and configuring actors are very often two sides of the same coin. This holds for smaller LMT companies in particular because they are due to lack of resources often not able to incorporate knowledge sources by simply buying appropriate organisations or hiring specialists and hence have to organise enduringly distributed "repositories" of relevant knowledge. What this means can be easily exemplified.

A small manufacturer of heating elements in our sample – *Freek* – pursues what one might call a second (or third) starter innovation strategy. To develop new product or process technologies themselves is not an option because it is considered as too risky and too expensive. Hence, they very carefully watch new developments presented at trade fairs and on the market and when they come to the conclusion that a novelty is interesting for them they start looking for a partner who can supply them with the appropriate technology. It is obvious that this strategy's success depends very much on the firm's configurational capabilities, that is, on both the available know-what and know-where and the accessibility of financial and other resources to keep this knowledge constantly up-to-date.

The latter tends to be not in the centre of the capabilities discussion. However, the case at hand illustrates that it is important to conceptualise financial and other material resources as constitutive elements of innovation enabling capabilities (cf. above p. 7): This particular firm's cash-cow are customised microcoil heating elements used for nozzles of plastic casting machines. The main component of these elements are tiny heating spirals with a diameter of one millimetre or more. The state-of-the-art insulation technology for them is with ceramic powder but this solution has reached its limits. When you miniaturise the coils further you need another insulation material – and an alternative process to apply it – to ensure safe and reliable functioning. Though there is currently no demand for smaller microcoil heating elements this may change sooner or later. Hence, the firm's engineers have experimented with alternative substances but they have not been able to do this very systematically. That they haven't is not caused by limited "absorptive capacity". Due to lack of time and resources they simply cannot afford proper technological research or methodical search for suppliers of alternative technologies just to be prepared for undetermined future demands. That is, there is a potentially critical weakness in the firm's configurational capabilities.

Pooling knowledge by configuring actors is an issue for other cases in our sample too. Such as the earlier mentioned tube producer. Very basic features of their products are actually determined elsewhere namely in the blast furnace of the steel mill they cooperate with and by their suppliers of welding material. In the "standard" business case, that is, when the demanded tube specifications can be met with standardised material the pipe company can treat their suppliers as a black box: they order a well-defined commodity and they get it. There is no necessity to make the relevant knowledge and competence a provider possesses explicit, it is embodied in the steel or in the welding wire etc. But when they need non-standard steel qualities communication is inevitable and the fundamentally distributed character of the tube manufacturer's knowledge bases becomes apparent. This organisation does not know everything that must be known to do the job alone; they draw on other repositories of knowledge on a regular basis. This is just another way of saying that the core company[16] functions as intermediate between steel mill, supplier of welding technology (and material) and customer. They know the client's requirements and at least in principle what the mill etc can do. Part of their engineers' competence is to be able to organise trade-offs between the various functional features expected from the product. In a way this implies an integration of knowledge distributed along the value added chain. And frequently also the generation of new knowledge: the definition of product specifications does quite often involve the definition of objectives for a collaborative development project. Critical for the success of the firm even in everyday business is the ability to handle this distributedness. In other words, part of their configurational capabilities accrue from their employees' qualification to communicate across the boundaries of their immediate field of expertise.

For some of the firms in our sample a major competence and one key to its success is the competence to timely and flexibly manage logistics. A striking example is *Lammhults*, a Swedish producer of high-end furniture for offices and public spaces. The components in their products are to 90 percent manufactured externally, most of them are based on standard components which are modified (upgraded) and they are – in spite of the company's small batch production model – delivered just in time. Storing costs are thus eliminated. The logistics dimension in this production system should not be underestimated. This small firm cooperates with up to three-hundred different actors (suppliers) during a year – for fabrics alone the company works with fifty suppliers. This small scale batch oriented system cannot work on a global scale: most of the supply chain is located within two-hundred kilometres from Lammhults leaving only the most standardised and the components used in most products to be purchased from global suppliers. Lammhults' products are bespoke products but at the same time to a large extent based on 3,000 modules of components and fittings. To be able to cope with this complexity the firm had had to develop capabilities to configure

[16] Core is meant here in a strictly topographical sense, that is, without any recourse to power or dependencies.

and manage a wide spread network of actors with complementary knowledge and expertise.

This case has some similarities with another furniture company in the sample: *Topstar* markets about 450 different models of swivel chairs, different in terms of functional features but also in colours, fabric of upholstery etc. But all these models can be put down to only twelve standardised basic types, so called assembly groups comprising the adapter-plate for the seat and its mechanics and fitting for the backrest. This functional core of a chair-type can be combined with very many different arm- or backrests, reels, upholstery etc. The assembly group principle does not only result in economies of scale and lower logistical effort. It also allows to deliver customised models for a single customer with very moderate additional costs. Thus, it increases the company's flexibility and helps to accelerate processes. As in the case of Lammhults far most of the components and the assembly groups are manufactured externally. Hence, rationalisation of internal processes is not (any longer) a major topic for Topstar. They are successful because – and as long as – they are able to configure suppliers along the value added chain and orchestrate these actors' activities. The quintessential point seems to be the firm's configurational competence, that is, the capabilities to capitalise on a system of co-ordinated links between actors.

Whether you focus on the cognitive (*ii*) or on the organisational dimension (*iii*) of configurational capabilities, the presented examples support our thesis that the economic success of LMT companies very often depends on the ability to bridge the gap between different knowledge domains and to generate new bonds between different entities. And they also evidence that this may mean rather different practical demands depending on the specific technological and / or economic environment a firm is part of.

(iv) (Re-)configure functional features and solutions (design)

The main business idea of several of the LMT firms analysed in the PILOT project is to create more or less customised solutions for advanced clients. In some cases this takes the form of one off bespoke solutions like the propulsion systems provided by *Finnscrew* or the pumping and heat exchange systems of *BCD Engineering* in Ireland. In other cases the customisation is more batch oriented like Swedish *Lammhults* which produce furniture for offices. In still other cases, like *Bahco Tools* and *Ostnor AB* which operate in a mass production environments characterised by mature technologies the design capabilities – in a wide sense – probably makes the differences between those firms which survive and those which do not.

The core technology in use by *BCD Engineering* is welding, and stainless steel welding in particular. The company, which is part of a small group of firms, designs, installs and validates stainless steel process systems of the kind used in breweries and other beverage firms, dairies, pharmaceutical, biotech and chemical firms etc. Most of these systems are bespoke solutions although often based on up- or downscaling of already tested subsystems. In their details many of the vessels, boilers etc are one off systems with individualised dimensions and specifications and with need for individual testing and validating. This is also reflected in the skill profile of the staff: a high portion of engineers doing the systems engineering and a large share of skilled welders and fitters among the shop floor staff. BCD's basic capability seems to be providing high quality and reliable bespoke process solutions – often more or less total engineering solutions – many of which are developed within a network of firms with processes which are well understood by BCD engineers.

Although the design and logistics capabilities of *Lammhults* seem to be interrelated thus creating the competitiveness of the firm, the design element deserves some comments of its own. In fact the design capability is not based on in house designers primarily but on orchestrating more or less closely working high quality design groups. That not only creates flexibility but also spillovers and externalities as Lammhult may benefit from what their subcontracting designers learn in other projects. Formerly thus, the design capability is based on purchased design services and Lammhults may have problems to report significant innovative activities performed in house.

As we have already argued above, *Bahco Tools* and *Ostnor AB*'s transformation of general technologies in forging and casting to high-end quality includes major design work. The tools from Bahco are thus designed to be convenient to use for hands of different sizes (there is also a gender aspect on this), to combine small size with high torque and precision and not to damage the nuts and bolts worked on. These are details of interest primarily for professionals, who use the tools frequently, and these groups have also been the target for the branding campaigns of the firm which has more than four-hundred ergonomically designed tools in the product catalogue. Ostnor, which is situated in the remote areas of the Swedish Dalecarlia region has historically benefited from a good staff recruitment situation and low labour turn over rates resulting in a skilled staff with accumulated tacit knowledge in connection with brass-casting which is the core process behind its products. Although design has become more important during recent decades, Ostnor has traditionally built its position on quality and on satisfying the needs from plumbers and professional installation people in the building societies. This market has also historically been sheltered behind real and formal trade barriers which has contributed both to Ostnor's strong position in Sweden and difficulties to obtain significant market shares in the rest of Europe. That may also be the reason behind the fact that there seem to be too many components involved for the production of so simple products as taps, cocks and valves and appliances for those.

The firms selected here from the set of PILOT case studies all show a variety as regards the character of the design element. However, they all fall within the broad framework of what Alexander (1964) called creation of fitness between form and context or what Simon (1996) labelled the optimisation between "inner" and "outer" parameters. In short it may be argued that there is more than one way to solve the problems these firms face. And customers may have different preferences in their selection of solutions, creating a window of opportunity also for creative firms in segments where mature and well known technologies dominate.

5 Conclusion

The aim of this paper has been to analyse the innovative capabilities within a group of firms which falls outside the high-tech classification of the OECD. Our basic hypothesis, stated in the introduction, was that also within mature industries recording low R&D and with unfavourable cost conditions at least some firms may develop capabilities which for a long time make them profitable and competitive. Our theoretical analysis has been supported by a more detailed study of a selection of the company cases examined within the PILOT project.

The studies substantiate that innovativeness, that is, the ability to create novel products and / or processes, is a critical success factor for the competitiveness of very many LMT firms. These companies are innovative and they have to be so to stay in the market. Hence, to build and permanently reproduce innovation enabling capabilities is necessary not only to flourish but often in fact to survive.

Our studies do not support the proposition sometimes put forward that non-research-intensive firms have a special mode of knowledge formation or innovation. The only feature shared by all of the case firms in the sample is that not a single one of them based their competitiveness on recent scientific findings. Innovation is here to a great extent the result of processes of transforming and configuring generally well known knowledge, components and technologies developed elsewhere. But in principle these are knowledge formation processes similar to what may be found in other firms labelled as high-tech or medium high-tech too.

Hence, the concept introduced here, though it was designed with a focus on experiences within LMT firms, may be useful for science-based innovation too; for the very reason that it aims at organisational and cognitive preconditions for the generation of novelty in general: it is based on the understanding that formal R&D is only one form of knowledge creation among others that are relevant for technical innovation. The concept of “innovation enabling capabilities” was designed to cope with this diversity.

The discrimination between transformative and configurational capabilities is strictly analytical, it helps to reduce complexity but is not an empirical description. We do *not* say that some firms need (or possess) more transformative capabilities and others mainly configurational ones.[17] If you want to configure distributed knowledge in novel ways you will usually have to transform it to make it match with the new configuration. Thus, transformative and configurational capabilities are two sides of the same coin; non-science-based innovations (*at least* non-science-based ones) require both.

But they are – therefore the distinction – not the same: To build up transformative capabilities requires investment in other things as compared to configurational capabilities. Transformative capabilities are about cognition and learning; they are based to a large extent on what Cohen & Levinthal (1990) called absorptive capacity. The analytical focus is here on an organisation’s ability to take up and process knowledge, in brief: to learn. Whether this is latest scientific knowledge or any other type of knowledge is not a matter of principle but an empirical question. What we call configurational capabilities comprises more than only cognitive learning conditions. To config-

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[17] Such a conceptualisation would evoke similar objections as the idea criticised above (cf. footnote 6) that LMT industries are dominated by practical knowledge and high-tech industries by codified knowledge.

ure functional demands and technical solutions (design) or actors and equipment may always entail learning processes. But we have above provided evidence that it often requires not only cognitive abilities.

Strikingly, all the firms analysed in the course of the PILOT project – even those working within mature and well known fields of technology – show some kind of specialisation; we may even talk about a capability creating at least some kind of variety compared to the competitors. Part of that variety is based on the firms' innovation enabling capabilities. These differences make the difference, not the amount of money spend on R&D. Firms all over the technology spectrum – low-tech as well as high-tech – may thus have opportunities to create solutions which are better or cheaper even if they face unfavourable cost conditions. This may give a company temporarily an edge compared to low-cost competitors before the rat race goes on again.

We should, however, not deny that the competition in the low-tech end of the economy is particularly tough. Some of our case study companies belong to the most threatened kind among manufacturing firms in Europe viz firms which combine globally well known technologies with large scale manufacturing of globally demanded products of a simple character and low degree of customisation. It is well known that the price pressure on such products and producers is extremely high.[18] Even if there are quality differences – the details of which we have not analysed – the large price gap creates significant incentives for potential high-end but low-cost producers to enter the market.

But the situation is not necessarily better in the high-tech end. In the strong international cost competition – not the least among the Chineses firms themselves - Chinese ICT firms upgrade to the high-end of the industrial sectors thus challenging Western firms also on that front. In the long run that will have an impact on the exchange rates but the macroeconomics of that process fall outside the focus of this paper. Here we restrict ourselves to the conjecture that to dampen the consequences of that transformation – which is going on already – there are strong reasons not to throw out the baby with the bath water. And that is to say that industrial and innovation policies in the European Union and its member states should focus on all innovative companies in the economy – not only on that science-based, or R&D-intensive, small segment we tend to label high-tech.

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[18] To give just two examples from our case studies. The cash-cow of Bahco tools are adjustable wrenches and competing varities of this product can be bought in Europe for about 15 percent of the prices charged by Bahco (cf. www.clasohlsson.se). The situation is similar for Ostnor; there is a clear potential also for taps, valves and mixers to be imported from e.g. China to Europe for approximately 15-20 percent of Ostnor prices or even cheaper than that (cf. Strömberg, 2005). These two firms are selected for illustration purposes only. We do not argue that they take an extreme position among the forty-five PILOT cases.

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