On the Relationship between the Evolution of Technological Firms and Their Knowledge Development Regimes

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Abstract **Differences in knowledge regimes and growth dynamics amongst four ideal types of knowledge based firms are analyzed. Two aspects of technological knowledge, technological opportunity and appropriability are traditionally seen as vital to understand the incentives for research and development activities in firms. However, they do not fully define the technology regimes, when one asks how the knowledge based firm competes. Therefore, the dynamic nature of firm capabilities and knowledge development in terms of expansion and in terms of deepening are also discussed. These two additional aspects of knowledge implies that even if all firms in an industry can be considered to be knowledge intensive these firms do also differ. Using cases of entrepreneurial start-up firms in Sweden, we illustrate whether our conceptual ideas of knowledge development help us understand the diversity and contradictions of firm evolution. Our finding is that firm evolution and capability development is dependent upon both the potential for expanding knowledge, such as by innovations, and by deepening the understanding within established knowledge, such as by learning. This implies that the shaping of a science based industry must be seen in relation both to the value of current knowledge and capabilities together with the sometimes only limited and temporarily advantages of radical innovations.**

Key words **knowledge regimes; firm evolution; bioscience; technology development**

Scientific and technological knowledge is increasingly understood as an endogenous key factor to explain the competitiveness and development of industries and individual firms[1]. An essential cornerstone is therefore the notion of the firm as an organization of capabilities and accumulation of knowledge of how to do things[2]. Much of the recent theoretical work on industrial dynamics has hence focused on the emergence and development of new firms in knowledge and technology intensive industries. The claim that we wish to pursue is that the nature of technological knowledge and knowledge based competition differ even within such a science based industry. More specifically, our research question is to try to differentiate a knowledge intensive industry, in the terms of differences in knowledge dynamics and to understand the firm evolution within these resulting sub-sectors.

1 Technological Regimes and Knowledge Intensive Firms

According to the classic Schumpeterian dichotomy, industrial dynamics and the development of firms are the endogenous outcome of technology and innovation-based competition. This dichotomy is traditionally stated as the dominance of small or large firms and the advantages of new entrants versus incumbents within an industry. At the centre of the industrial structure is hence the endogenously and path dependent technological activities of firms.

From this research tradition, the two central concepts for understanding how knowledge and innovations evolves are the range of technological opportunities and the variety in appropriability of knowledge. These two concepts were originally developed to capture how scientific and technology knowledge are driving forces behind economic development in different sectors at the meso-level. The first concept, opportunities, refers to differences in the marginal rate of technological return on R&D investments such as the likelihood of innovating[3]. Differences in technological opportunities hence conceptualize why technology advances are much faster in some sectors than in others[1-4]. The second

Received 2006-09-15

concept, appropriability, refers to the incentives and value that the firm obtains from knowledge investments such as R&D. The level of appropriability hence explains that despite soaring technological opportunities, firms in different sectors may have differences in their incentives and ability to obtain returns in front of competitors[5].

In addition to technological opportunities and appropriability, it has been argued that the industrial structure and evolution of firms reflects the outcome of sector specific, technological regimes[6-7]. The different technological regimes reflect specific properties of the technological knowledge – not just the level of technological opportunities and ease of appropriability per se. Levin, Klevorick et al. were able to identify several appropriability mechanisms due to differences in knowledge dynamics in different industries, which were used in order to protect and profit from innovations[8]. Additional aspects of how technological knowledge develops hence may help us problematize the role of knowledge in firms. These additional aspects thus relate to the strategic value of knowledge of the firm and how firms are likely to co-evolve with the technological knowledge development.

The biotechnology industry appears to be a good industry to analyze how technologies and the knowledge regime are related to firm evolution. The biotechnology industry emerged in the 1970's as the result of disruptive innovations around DNA and monoclonal antibodies, mAbs[9]. Biotechnology firms can be used as prime illustrations of the theoretical ideal of a firm with a low dependency on tangible assets, and a high dependency upon knowledge to compete. Knowledge intensive firms are hence here defined as firms with a low fraction of tangible assets. These science based firms are interesting due to their primary reliance on knowledge and the development thereof, and can be said to operate as a general model of future technology based firms[10-11]. Elsewhere, expanding from the OECD definition, we have argued that the biotechnology industry consists of an expanding and highly interrelated knowledge base, involving many scientific and technological fields, which is relevant to many industrial sectors[12]. Based on this, we have put forth the claim that biotechnology industry consists of many highly interrelated sub-sectors such as medical devices, pharmaceuticals, agriculture, and so on. Stressing sub-sectors implies that each may have different knowledge regimes, dependent upon the type of sector in which biotechnology is applied.

2 Theoretical Propositions

We will limit our theoretical interest to how and why the different aspects of technological knowledge development relates to the evolution of knowledge based firms, including their ability to compete and to survive in the longer term. We will therefore discuss two propositions of how technological knowledge evolves which provide an addition to the existing concepts of technological opportunities and appropriability. In this conceptual model, technological knowledge can simultaneously be constructed either by gradual, incremental knowledge development or more radically discoveries and exploration. Theses two aspects on how different technological knowledge develops were initially derived by Stankiewicz[13-14]. However, we will not limit us to see them as working in isolation but instead simultaneously and in relation to the development and growth of the firm.

The first argument regards the progressive deepening of knowledge within in a technological domain. This represents the strengthening and increasingly structured nature of technological problem solving as technological knowledge evolves. Activities within such a technological domain are increasingly built on cumulated past experiences and relatedness which guide future development[15-16]. Past activities are thus leveraged and exploited as they are underlying the evolved firm capabilities. As knowledge in the technological domain deepens, problem solving becomes gradually more stable and reliable. This process of technological learning involves a constant struggle to structure and reduce the complexity[14]. A deepening technological development may further lead to the establishment of an expertise within the domain who masters the constructive and synthetic development of the technological activities. The deepening knowledge development includes the formulation of a language, decomposing of problems into sub-problems, establishment of heuristics and may result in a partially codified knowledge. The technological knowledge of firms may potentially become institutionalised in practices and the specific organization of the firm, forming firm specific capabilities. The focal point is hence about the potential for firms to be involved in technological learning and refinement in a process where technologies simultaneously are being reused, exploited and improved (e.g. re-combined, analogies and extrapolations) to solve related and reoccurring problems and adapt technologies to local, specific contexts[17].

Proposition 1 Technologies differ in their potential to be further developed within their established knowledge domain.

The second argument regards the expansion of the technological knowledge domain itself. The expansion of the technological knowledge domain is according to Stankiewicz essentially a process of isolated and unguided, discovery[13-14]. The expansion of the technological knowledge domain is hence fundamentally different from technological knowledge deepening. In terms of development, technologies evolve by serendipitous discovery and exploration rather than by deliberate design and learning. Expansion introduces newness and widening of the current technological knowledge domain but may also open up for later deepening, detailed understanding. The expansion of knowledge in a technological domain is neither the result of the application of science and information nor the result of feedback and situated learning; instead such expansion is dependent of the available experimental setup and the gradual development of expertise in search technologies. The technological development is hence affected by isolated discoveries and available instruments rather than a well developed knowledge of the technological domain per se. As a result, the technological development is mainly driven by the potential for experiments rather than by an synthetic activity[18].

Proposition 2 Technologies differ in the potential to be radically developed with a fundamental expansion in their knowledge domain.

3 Research Method

Based on our two derived propositions outlined above, we have chosen theoretically sampled, case studies of four science and technology based firms. The four firms were explicitly chosen to illustrate our discussion and the resulting ways in which firms co-evolve with the development of technological competencies and capabilities. The four firms are all involved in what can be defined as the Swedish bioscience industry and biomedical innovation system[19]. All of them are performing activities corresponding to dif, as shown in Fig.1.

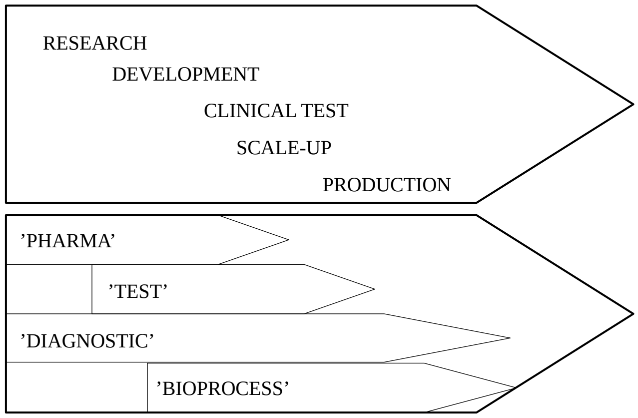

Fig.1 The 'biotechnological value chain' and the activities of the four case firms

We have chosen four theoretically sampled cases of firms in that they have some degree of similarity but yet variations, highlighting the internal diversity of knowledge based firms[20]. These illustrative cases are hence used to strengthen and explain our theoretical propositions rather than derive and create new theory directly grounded in empirical work. As such our research method corresponds to one of the usages of case studies advocated in the Ref.[21]. Each case has been analyzed using a variety of information, including quantitative and qualitative sources. Our aim has been to develop a detailed understanding of the evolution of the four firms and to analyze the firm as an example of different knowledge dynamics in different sectors. Hence, each case study has included a variety of complementary empirical methods and indicators to find and triangulate appropriate data for the concepts of interest.

Firstly, we needed to find a way to specify and differentiate the scientific and knowledge assets of specific firms. Given the lack of sales in this industry, financial indicators are difficult to use so we have used knowledge performance indicators. We use the number of patent and publication as indicators of scientific and technological output for the firm. The knowledge ego-networks are analyzed, primarily based on formal points of collaboration through patents and research-publications. Further on, different patent classes used an indicator of the potential for combining or diversifying into related knowledge areas. We also needed to find a way to specify and differentiate the innovative efforts and successes facing the specific firms. For these cases, we used qualitative data, about the specifics of the innovative activity of the firms but also content in annual reports, public and business press. We were particularly interested in whether, the relationship between new products and existing products and activities.

Secondly we were interested in how the firm was able to translate the development of knowledge, into growth and evolution of the firm. Such an indicator should capture the growth of firms either by sales, size and employees or by geographical aspects such as expansion nationally and internationally. Indicators of growth are measured by figures on sales and employees from annual reports and changes thereof. However, sales are rather misleading in bioscience industry since the return of licensing and co-development agreements can by highly fluctuation over the years. Measures such as employees, R&D and non R&D spending are much more stable. More qualitative material arises from the narratives of the development of these four firms.

4 Illustrating with Four Case Studies

Four firms are here chosen to illustrate the ideas underlying the propositions. These firms highlight the differentiated evolution of knowledge intensive firms upon the diversity in their technological knowledge development.

4.1 Test

The case firm "Test" was founded as a small clinical trial company by an experienced manager from a Swedish major Pharmaceutical firm. During the initial years 'Test' gradually developed a capability of clinical and pre-clinical product development and gained knowledge in regulative affairs, data management and statistics as the initial projects unfolded. Simultaneously "Test" established relationships with the Swedish regulatory authority, and several university hospitals in Sweden. As the numbers of ongoing clinical projects after the year 2000 were reduced, "Test" was forced to cut the number of employees. In 2005 "Test" were acquired by a competing Swedish firm.

4.2 Bioprocess

The history of "Bioprocess" can be traced back to the beginnings of the 1960's where it is created as a business unit within a major Swedish food and agricultural company. In the mid 1980's "Bioprocess" acquired a patent from Russia, and became production unit for the biological production of an amino acid used in animal feed. The acquired skills in biological production lead to a strategic renewal in the early 1990's. Following this redirection towards the pharmaceutical market, several long term contracts are entered for the production of monoclonal antibodies and other biologically produced active pharmaceutical ingredients.

In 1997, another small Swedish biotechnology firm acquired "Bioprocess" with the goal to work upon the scale-up and production of their proprietary biological product. During this time "Bioprocess" maintained their contract business activities in scale up and contract production. In addition, "Bioprocess" also took on the responsibility and integrate purification and additional downstream processes to complement its commercial offers.

In 2002 the scale-up and development of production methods for the parent firm was finished and "Bioprocess" was once again sold, this time to a major pharmaceutical company. The firm, now as a separate business unit, constantly maintains its focus upon scale-up and commercialization of biotechnological production. The external knowledge development network of "Bioprocess" showed a modest diversity and low intensity, as shown in Fig.2.

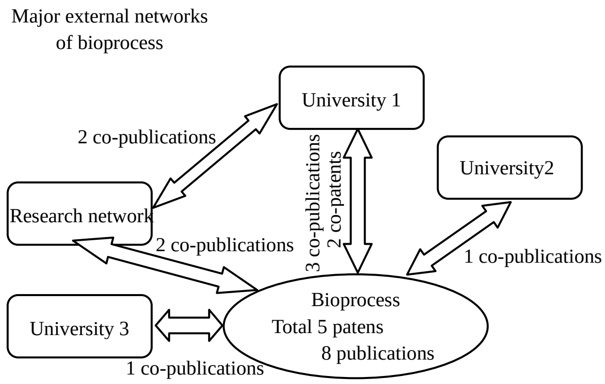

Fig.2 The network of 'Bioprocess'

4.3 Pharma

The case firm "Pharma" was founded in 1998 around the goal to develop pharmaceuticals targeted towards a special type of cell receptors which had been characterized in a university based research project. Immediately from the start ‘”Pharma” acquired competencies in combinatorial chemistry and chemometrics, an information intensive chemical method used in the search for pharmaceutically active entities from a second university. In addition, the firm employed a few researchers with experience from the two major pharmaceutical firms located in Sweden. Further on, an external research organization was regularly contracted for the synthesis of their chemical library. After only a short period the lead project entered the clinical stage. To expand its activities, a research collaboration was entered with a major international pharmaceutical firm, and small research firm was acquired during 2002. However, “Pharma” ran into financial troubles as one of the majority owners refuses to inject more capital. As a result, “Pharma” was forced to restructure, and reduced the number of researcher and decides to explicitly focus upon the initial prime project. Finally after one year of financial struggle “Pharma” declared bankruptcy. The remaining intellectual property rights, including the different chemical libraries were sold to an additional research firm which took over the development of some of the projects. The external knowledge development network of ‘Pharma’ showed a low distribution but high intensity, as shown in Fig.3.

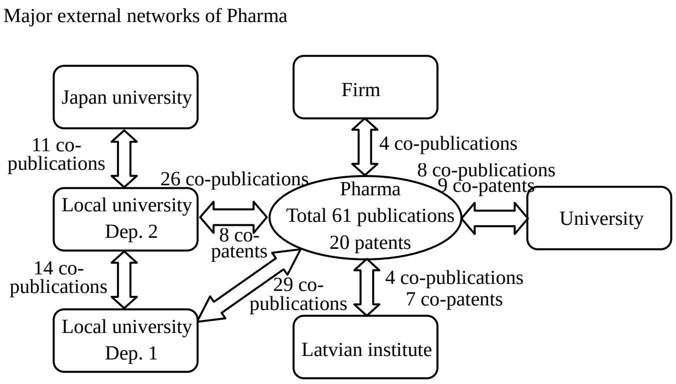

Fig.3 The network of ‘Pharma’

4.4 Diagnostic

The fourth firm, “Diagnostic” was founded in the mid 1980’s around a initial university developed, and clinically tested, diagnostic application based on monoclonal antibodies for the testing of various cancer forms. The firm immediately focused on initiating commercial production and marketing of the first version of a simple test kit. During the 1990’s new products were continuously developed and introduced for detection of various cancer forms. These products were sold to both hospitals and distributors in an increasing number of countries.

Together with the test kits, “Diagnostic” developed a second business component where reagents, were sold to external firms, which in turn manufactured products for additional applications. “Diagnostic” also engaged in a radical product development strategy based upon technologies around mRNA. In addition, a second product generation was introduced, which broadened the applications from cancer diseases towards various brain disorders. The external knowledge development network of “Diagnostic” showed a high distribution but modest intensity, as shown in Fig.4.

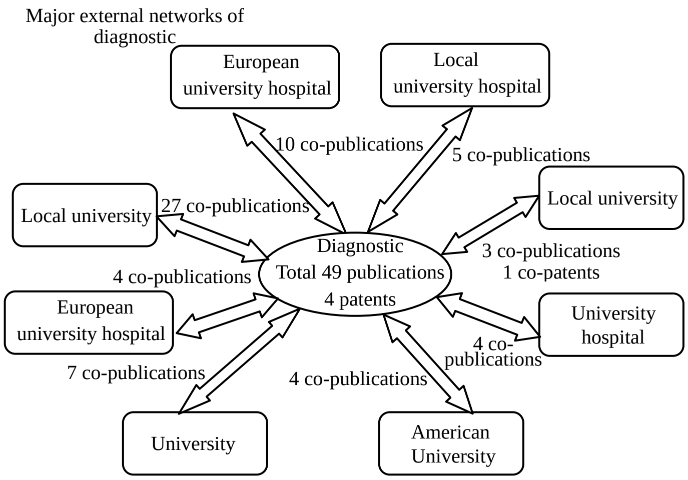

Fig.4 The network of ‘Diagnostic’

5 Differences in the Technological Knowledge Development

The four cases illustrate the differences from the perspective of deepening and expanding technological knowledge domains. This first case firm, “Test” illustrates that the build up of capabilities, and reuse of knowledge within stable activities is an important category in a science based industry. Such frequently demanded and necessary capabilities may remain fairly static and yet competitive. The case of “Test” thus represents a firm with neither deepening nor expanding technological knowledge domain. The firm has shown a low success rate through radical innovativeness, neither has the firm developed its technologies by increased detailed understanding and learning. “Test” has built up and maintains close organizational links with different clinical actors and emphasizes the importance of such stable external relations. No external relations directly aimed at developing technologies can however be found, nor any patents. Nevertheless, 'Test' has not been without attempts to innovate. Further on, "Test" has tried to compete by diversifying its provided services by entering relationship by two additional firms in the clinical service industry. These efforts have however in reality not changed the way "Test" performs its activities. The motivation for the final merger is neither based upon any reasons for future knowledge development; instead the goal is to complement the existing services, expand the geographical coverage and reduce the vulnerability of the resulting entity to individual customer relations as "Test" previously had struggled to maintain stability in the demand for its services.

The second case firm "Bioprocess" illustrates a firm which has rather broad technological competencies, but yet has a low rate of truly radical innovations. The firm has emphasised learning and the deepening of their expertise in the engineering and scale-up of biological production processes. The firm has managed to transfer knowledge from project to project resulting in an accumulation of gradually increasing engineering knowledge. However, "Bioprocess" also maintain relationships with universities and public research organizations (as Fig.2 shows). These external scientific relationships, as well as the patent activities, are rather diverse. 'Bioprocess' combines each development project, leveraging upon its existing knowledge base, with the gradual development and increased understandings for gradually opening up future projects. The case of "Bioprocess" can be analysed as follows: new knowledge arise mainly during the development and productive usage of technologies. The resulting deepening of the technological knowledge can hence be essential for further activities and competitiveness, as "Bioprocess" in general remain is focused upon production and up-scaling of biological processes. Essential for the knowledge development of this firm are hence both the ability to integrate external knowledge as well as gradually increase the evolving understanding of the knowledge domain. Internal research and radical expansion of the knowledge domain has however been less emphasized.

The third case is a firm with strong focus on expansion of knowledge and radical innovations. This is the case for "Pharma" which received the initial idea from the local university and maintained strong linkages with the initial inventors. "Pharma" are partially also dependent upon new research technologies and new possibilities for problem solving such as chemometrics. From the data of patents and publications the technological evolution can be described as expanding but not deepening. This is also reflected in the relationships and network structure of 'Pharma' which is characterized of high intensity, strong ties, but with few external actors (as Fig.3 shows). The case of "Pharma" can be analysed as follows: The firm is dependent on research for the initial source of innovations. They also have a highly specialized technological base and an innovative driven activity together with generic research technologies. 'Pharma' hence combines relatively unique knowledge and idiosyncratic radical concepts with new but rather generic research technologies. In terms of deepening, learning within the specific knowledge domain, the firm fails to leverage any of the developed knowledge, as all sequential research projects gradually is closed and the organization finally completely dissolved.

Finally "Diagnostic" is a firm which exemplifies the occasional fusion and amalgamation of radical new ideas with existing technological knowledge domain. The firm has managed to gradually improve their initial competencies while at the same time successfully introduce and integrate a radically innovative new product. As such their technological knowledge both deepens and expands. The patents of "Diagnostic" show a rather extensive technological diversity, although the numbers of patents are low. The external relationships, within research and development, also show an increasing diversification (as Fig.4 shows). This is seen with several independent relationships, both between different universities as well as between different users and applications of the developed technologies. With the event the new innovative technology "Diagnostic" radically expanded their available knowledge domain. The case of "Diagnostic" shows that expanding knowledge domains, arising under radical innovations is potentially essential for further product generations if it can be integrated with existing competencies. The technological knowledge for "Diagnostic" is thus interpreted as both deepening and expanding as the firm is able to transfer developed capabilities to integrate new generations of innovations. "Diagnostic" has hence gone from a single-project research spin-off, to product and technology diversification with different projects with partial technological overlap.

5.1 Knowledge Dynamics

For two of the firms, “Diagnostic” and “Bioprocess” local learning and new combinations open up new opportunities and increase competitiveness of the firms. These two firms have maintained a diverse set of knowledge internally as well as through external relations. For the other two firms, “Test” and “Pharma”, leveraging and improving their capabilities is not seen, they represent a domain with low levels of learning. For them, a wide distribution and diversity of knowledge networks is absent, either because overall low activity, such as in the “Test” case, or because of the existence of a few but focused activities as in the “Pharma” case, as shown in Tab.1 and Tab.2. The dynamics of these knowledge domains hence relate to the findings of social network theories on innovation which states that, few but strong ties are related to the exchange and feedback upon specialised knowledge while a more diverse and weak ties are used to get arbitrage and early access to new information and knowledge[22].

Tab.1 Firm innovation and knowledge activities

Company	Patent* activity:	Scientific publication activity***
Bioprocess	2/2/4	7
Test	-/-/-	-
Pharma	(1**)/7/20	58
Diagnostic	1/1/5	53

*Patents are measured USPTO Granted / USPTO Applications / esp@cenet ‘Worldwide’. **The patents of ‘Pharma’ has been transferred to other firms. *** Data from ISI Web of Knowledge.

Tab.2 Growth and evolution of the four case firms

Company	External knowledge ego-network structure	External networking activity
Bioprocess	Distributed	Low
Test	Low	Low
Pharma	Focused	High
Diagnostic	Distributed	High

The second proposition is the perspective of radical innovation and technological knowledge domain expansion. As such the emphasis and relationship with past activities and developments vary. Both “Pharma” and “Diagnostic” have successfully invested in radical new product development, partially unrelate with previous knowledge, as shown in Tab.3. These radical innovations have been made in close relationship with universities. The other two firms, “Test” and “Bioprocess”, have put significantly lower effort in and have had less success with introducing any real novelties.

Together these two aspects of deepening and expanding, knowledge dynamics relates to the evolution of the four firms. The technological differences across the four firms are linked to the firm dynamics in terms of size development, as shown in Tab.4. The two case firms which have deepening technologies demonstrate slow but steady growth. For the other two case firms, growth has been dynamic and rapid, but also turbulent. These two firms have been forced to increase as well as decrease the number of employees.

Tab.3 Growth and evolution of the four case firms

Company	Successful incremental development of capabilities	Successful radical innovation
Bioprocess	Yes	No
Test	No	No
Pharma	No	Yes
Diagnostic	Yes	Yes

Tab.4 Growth and evolution of the four case firms

Company	Founding year	Growth in size
Bioprocess	60ies	Slow/Steady
Test	1990	Rapid/Turbulent
Pharma	1998	Rapid/Bankruptcy
Diagnostic	1984	Slow/Steady

6 Redefining Technology Knowledge Regimes

The two conceptual dimensions presented above highlight fundamental knowledge related differences and contingencies in the evolution of individual knowledge intensive firms. The first dimension capture the possibilities to recombine and integrate knowledge to solve related problems across a “given” technology domain. This dimension thus stresses technological knowledge development as having more or less potential for incremental development and adaptations. The second dimension relates to the novelty and the expansion of the knowledge domain in itself, emphasising radical innovations as qualitatively different from the gradual progress of incremental understanding. Combining these two dimensions, expansion and deepening, of the knowledge domain hence result in four quadrants which are defined by their specific combinations of technological knowledge development. The differences in the knowledge evolution thereby impact how firms can compete over the long run as shown in Tab.5. These two dimensions thus underline the relationship between different contingencies for firm level competitiveness and growth.

Tab.5 The derived ways in which biotechnology firm competes based on the knowledge

	Low extent of knowledge domain deepening	High extent of knowledge domain deepening
High extent of knowledge domain expansion	Isolated Discovery	Discovery and Design
Low extent of knowledge domain expansion	Replication	Design

The first resulting quadrant represents the introduction of novelty in a domain of well established and developed technological knowledge. Such additional knowledge development greatly expands the available options for the firm and gives potential for frequent re-combinations and additional incremental refinements. The expansion of the technological knowledge domain gives rise to a wide range of new options and potentially increased flexibility for the firm. Within such technological regime firms struggle to integrate radical innovations as well as continuously upgrading their current competencies[23]. Firms accentuate a diversified network trying to integrate and match external knowledge with their internal capabilities for further development. Within this kind of technological domain opportunities are generally considered to be high. Appropriability for firms may both be ensured with patent protection but also from other first mover advantages such as the potential for additional learning and leverage of accumulated knowledge.

The second resulting quadrant represents the discovery of more isolated novelty which breaks away from the prevailing design practices and reaches outside the current technological knowledge paradigm. If the innovative technology is not well understood and relatively unrelated to previous knowledge, the emerging technological opportunities are here rapidly depleted. Even successful innovations might hence give rise to a “lucky shot” phenomenon, as gained knowledge rarely can be incorporated into any sub sequential development within the firm. In these cases radical innovation and the extension of knowledge can often not be further leveraged upon, and improved product generations are seldom seen. Firms active within this kind of technological knowledge domain will hence have a high risk strategy with frequent failures, causing a turbulent and dynamic industry. Opportunities depend primarily upon the development of search technologies. Due to the isolated nature of knowledge development other appropriability mechanisms besides patents have a rather low importance, learning and additional product generations are thus seldom generated.

The third resulting quadrant represents a knowledge domain with the combination of low novelty and a low degree of deepening in the technological knowledge. This combination results in a rather static and simple knowledge domain with well established and standardized practices. The potential for re-combinations, learning and refinements is hence already depleted and firms mainly replicate current practices. Firms active within this type of knowledge domain are thus dependent upon matching the external demand and have problems of renewal when markets halters or reduces. Competition by introducing innovations and additional development is negligible. Successful firms instead adapt, expand and shrink, according to current market demands but maintain established key assets, such as important external relations and developed internal procedures.

The fourth resulting quadrant represents a technological knowledge domain undergoing gradual development towards an evermore detailed understanding. The knowledge domain involves the potential for incremental refinement, learning and recombination of design within the current technological paradigm. Firms within such regimes benefit from the build-up of internal knowledge and capabilities as well as internal and external relations. The participation and integration of external knowledge is essential. Appropriability is generally seen as high, mainly due to external ambiguity, local learning and the establishment of stable organisational structures. However, patents have a low degree of success as each project aims at solving the specific and contextual problems.

7 Conclusions and Implications

From an evolutionary perspective on innovation and knowledge in technology and science based industries, we start by assuming that economic competition is driven by the opportunity of actors, especially different firms, to compete by knowledge based capabilities. While that may be the general story, these four case studies demonstrate the difficulties firms face in actually benefiting from knowledge as an evolving asset. Thus, we have argued, that the nature of the specific technological domain explains the evolution of firms rather than their knowledge intensity per se. Firms are dependent upon their specific characteristics of technological knowledge development and they may maintain competitive advantage without innovations, as well with innovations. This suggests that how firms compete with respect to knowledge assets differ. These results show that the relationship between technological activities and firm evolution indeed do differ even within a strict science based industry. These results also coincide with emerging evidences on the weak linkages between scientific production (articles and patents) and the ability of the knowledge intensive firm to grow and generate profits contrary to general beliefs[24].

The two aspects of the knowledge intensive firms are hence 1) The extent to which innovative activities and focused knowledge extension can be said to differ from; 2) The further deepening knowledge, technological development and understanding. These two aspects imply that if all firms can be considered to be highly dependent on knowledge, their evolution and growth differ widely. Such aspects besides the stringent definition of high/low opportunities and high/low appropriability have implications both for the individual firm as well as for the industrial dynamics by creating entries, exits and sustainable knowledge accumulation within firms.

The characteristics of knowledge dynamics are most extreme in fast moving industries where the rate of change is high. In such industries a great extend of the value ascribed to knowledge refers to the potential for further development rather than appropriation of current activities. In the firms studied here, the rapid technological dynamics emphasize this duality between creation and build-up of future activities as well as the continuously reconfiguration and relevance of present activities. This duality, between benefiting from both future and the present activities is essential to the notion of a knowledge-intensive firm. This diversity also implies that science industries (potentially) only is unified by the emphasis these firms put on scientific and technological knowledge as the main asset of the firm. From a policy perspective the findings imply that science based industries and firms cannot be treated as homogenous. The individual firm is highly dependent upon the idiosyncrasies of its technology and competencies, creating great intra-industry variety in the evolution of firms. Overly focusing upon innovations, start-ups, and rapid growth is not the whole story. To radically innovate and expand knowledge domains per se is important, but as innovation studies often show, to form and retain links between past technological knowledge into coherent understanding might be even more important for opening up for further development and incremental innovations.

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Brief Introduction to Authors

BRINK Johan was born in 1976. He graduated from Chalmers University of Technology in 2001. From September 2005 to August 2006, he spent time as a visiting Ph.D. student at the Business School, University of Queensland Australia. From 2002, he has been a Ph.D. student at Chalmers University of Technology, Sweden. His research activities have been concerned with growth and development of knowledge intensive research firms within the life-science industry.

MCKELVEY Maureen was born in 1965. Since 2001 she has been Professor (Chair) in Economics of Innovation, at the Department of Technology Management & Economics, Chalmers University of Technology Sweden. Among other activities she has been a visiting researcher at AEGIS (Australian Expert Group on Innovation Studies), University of Western Sydney, Australia, July 1999 to July 2000 and a visiting researcher at SCANCOR, Stanford University, USA (July 2002). He also serves as a elected board member for the International Joseph A. Schumpeter society and has participated as member in the advisory Committee for the EU Commission, Joint Research Centers – IPTS “Biotechnology for Europe”. Her field of study includes management and economics of innovation.