Innovation as Creative Response. Determinants of Innovation in the Swedish Manufacturing Industry, 1970-2007

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Abstract

This doctoral thesis examines the driving forces of product innovations in the Swedish manufacturing industry during the period 1970-2007. Specifically it examines whether and how extent innovations have been the creative response to positive factors, such as new opportunities and obstacles related to their exploitation, and negative factors, such as economic, environmental and organizational problems. To this end, a newly constructed database, SWINNO, containing more than 4000 innovations is explored. Using this database, the thesis studies the determinants of innovation activity in firms, industries, in development blocks and on the macro-level. The results point to the existence of two main patterns. Innovations aimed to solve economic, environmental and organizational problems have culminated during the 1970s, reflecting the deep economic, social and environmental character of the structural crisis. Firms in crisis struck industries responded by developing new products. Some of these innovations have been parts of development blocks solving obstacles to the introduction of emission control and renewable energy technologies. Innovations exploiting opportunities have culminated in the mid-1980s and towards the beginning of the 2000s. These have formed development blocks surrounding ICT and biotechnology, evolving by way of the exploitation of opportunities and the solution of technological imbalances. Opportunities have been salient driving forces among entrant and incumbent ICT firms, but evidence was also found for a role played by decreases in profitability in inducing search for new products and markets.

Key words

Innovation, creative response, structural change, development blocks, transformation pressure, industrial transformation, manufacturing industry, Sweden.

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This thesis revolves around a large scale database constructed together with Karolin Sjöö. Together we have collected and categorized the data and carefully weighted the methodological pros and cons. I am deeply thankful for the hard work, enthusiasm and resourcefulness that Karolin has brought to this process. Thanks also to Johanna Conradsson, Björn Eriksson, Josephine Fischer, Emelie Hane-Weijman Jansson, Johanna Jeppsson, Anne-Sophie Larsson, Jonas Lilja and Jacob Littorin who assisted in collecting parts of the primary material.

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Contents

List of Tables

List of Figures

1. Introduction

The importance of technological change in economic development during the past centuries can only barely be exaggerated. One of the most essential events in economic history is the drastic shift in living standards and economic growth and the restructuring of society that followed the first industrial revolution, accredited to the invention of the steam engine, cotton spinning machinery and the waves of technological innovations that followed from their breakthrough. Since the first industrial revolution, society has transformed from an agrarian economy to a service-oriented capitalist economy. This development has been intertwined with successive waves of technological change. At the basis of a second industrial revolution was the invention of the electric motor and the combustion engine, enabling the electrification of factories and homes and the expansion of infrastructure based on automotive vehicles that culminated in the post-war era. The third industrial revolution marks the beginning of the period studied in this thesis. Microelectronics enabled the wider diffusion of computers and electronics and has brought about a transformation of society that was hardly imaginable when Intel launched the first microprocessor in 1971.

1.1 Innovation as creative response

While the role played by technological change in economic development is arguably well understood, the driving forces underlying it are much less so. Uncovering the historical causes and incentives of technological change lie at the core of explaining "economic development", by which is understood the generation of novel historical situations and societal relations. It is almost needless to say that explaining the first industrial revolution has been a core debate in economic historical research (e.g. Crafts, 1985; De Vries, 1994; Mokyr, 1990; Allen, 2009; Mokyr, 2009). The understanding of technological change as influenced by socio-economic factors has however not always been obvious. In various strands of economic theorizing technological change was for a long time treated *de facto* as exogenous to the economic mechanism. More recent contributions in economic theory have from a range of different perspectives recognized that technological change may be conducive to changes in the economic environment.[1] However, there is still no consensus of what factors influence innovation activity over time, in firms, industries or economies. This fact motivates a broad historical empirical approach. This thesis approaches the issue on the basis of a general notion of *innovation as creative response*.

The act of invention has been attributed to curiosity, necessity and opportunity. Systematic *innovation*, however, is arguably a modern phenomenon. Before the scientific revolution of the 18th century inventions were few and far between and did not occur in a systematized manner. Industrial society meant a transformation of the socio-economic function of invention and the opportunity to invent.[2] The emergence of a separation between the social practices of the inventor and the entrepreneur has motivated a distinction between invention and innovation. The term "innovation" as opposed to invention, refers to an economic process: an economic agent exploiting an invention, and making a profit from it by bringing it to market or using the invention in a line of production (Schumpeter, 1939, pp. 84-85). Innovation may thus be understood as an intrinsic part of the economic process of capitalist development. Innovations change the prerequisites of economic activity, while resulting from the response of agents to changes in the economic conditions.

The fundamentals to a theory of endogenous innovation was supplied by

[1] Solow (1957) introduced the notion of total factor productivity or the so-called Solow residual as the growth in aggregate output that cannot be accounted for by the growth in production factors (labour and capital in the simplest models). In more recent years contributions to the economic theory of growth have attempted to account for technological change: the so-called endogenous growth theory and evolutionary growth theories (see Verspagen, 1992 and Verspagen, 2005). These contributions model innovation as functions of economic data, such as the stock of knowledge or the productivity of researchers (see Arrow, 1962; Romer, 1986, 1990; Aghion & Howitt, 1992; Grossman & Helpman, 1994, or as mutations influenced by selection mechanisms (Nelson & Winter, 1982; Metcalfe, 1994).

[2] This was observed by intellectuals of the 19th and early 20th century. Karl Marx remarked that "Invention has become a business, and the application of science to direct production itself becomes a prospect, which determines and solicits it" (Marx, 1973, p. 704). Alfred North Whitehead similarly wrote that "the greatest invention of the nineteenth century was the invention of the method of invention" (Whitehead, 1967 [1925], p. 96).

Joseph Schumpeter's "The creative response in economic history" (1947) in distinguishing between 'adaptive response' and 'creative response' to changes in economic conditions. The former refers to measures taken within the "existing practice" of an economy, industry or firm, whereas the latter denotes measures taken "outside of the range of existing practice" (Schumpeter, 1947, p. 150). The view of innovation as a creative response to changes in the conditions of firms, industries or economies may function as a uniting framework of the accounts that aim to explain the economic driving forces of innovation. Response may be related to a wide host of different factors. The factors underlying creative response may be understood as being on the positive or negative side of economic transformation (Dahmén, 1950). They may pertain to conditions immediate to the firm, the opportunities brought about by scientific or other advances or a perceived societal or techno-economic problem that requires the overcoming of obstacles.

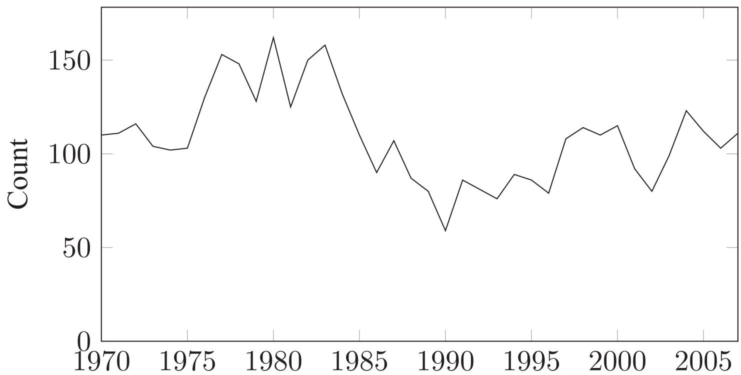
The notion of innovation as creative response to positive and negative factors lays the foundations of this study.

1.2 Innovation in the Swedish manufacturing industry, 1970-2007

This thesis describes and examines the driving forces of product innovations during the period 1970-2007 in the Swedish manufacturing industry. Sweden is an apt case for the study of innovations. For a long time Sweden has been one of the highest ranked countries in the world in terms of research and development (R&D) expenditures and other innovation indicators (OECD, 2005). Sweden has at least since the 1920s been an internationally high-ranking producer in the fields of electric appliances, telecommunications and automotive industries, to name a few. Large R&D intensive multinational firms, such as L M Ericsson, ASEA (later ABB), Volvo and Saab-Scania, Tetra Pak and Astra (later Astra Zeneca), have traditionally played a significant role in industrial development, close to the frontier of technological progress. SKF's spherical roller bearing (1919), The AGA cooker (1929), Astra's Xylocain (1948), ASEA's High-voltage direct current (1951), Tetra Pak (1951)[3], Elekta's gamma knife (1967), Ericsson's AXE system (1976), Saab-Scania's turbo motor (1976) and Astra Zeneca's

[3] A tetrahedron-shaped paper packaging innovation launched by the firm with the same name.

Figure 1.1: Total count of innovations by year of commercialization in the Swedish manufacturing industry, 1970-2007.



Losec (1988) are a few examples of cutting-edge innovations developed by Swedish firms (Sedig & Olson, 2002; Wallmark & McQueen, 1988).

In order to study the determinants of innovations, this work employs quantitative and qualitative data from a new database, SWINNO (Swedish Innovations), covering 4140 product and process innovations in the Swedish manufacturing industry (Sjöö et al., 2014). The database captures significant innovations developed by Swedish firms, launched on the Swedish market. The database has been constructed by Karolin Sjöö and the author of this thesis.

A fundamental result of this database is the pattern of the counts of innovations launched over the period studied. This pattern is shown in Figure 1.1. The observed pattern suggests that there was ample innovation activity during the 1970s, a trough in the early 1990s and an ensuing recovery.

During this period the Swedish manufacturing industry has, like in most other industrialised nations, seen a thoroughgoing process of transformation in which new industries have come to the fore, exploiting the vast opportunities of the third industrial revolution based on micro-electronics. Other industries have come under a strong pressure to transform. Some industries, shipbuilding and textiles in particular, were struck hard during the 1970s. Other industries have struggled with the transition to a more environmentally sustainable production system.

Based on the SWINNO database, Sjöö (2014) investigates the changes in volume and character of innovation in relation to received historical accounts of industrial transformation. The study argues that innovations were not only more numerous but also more novel during the 1970s and 1980s. Two major trends are obtained from the SWINNO database. Innovation output has shifted from being concentrated to machinery and other capital goods industries to fields as electronic instruments, telecommunications and software. Moreover, the type of innovating firms have changed from a clear large firm dominance towards small firms (see chapter 6 in Sjöö, 2014 for a detailed analysis). The fundamental patterns observed in the SWINNO database raise several questions about the character of innovation and what economic, social and other factors drove innovation activity over time and across industry space. The current thesis therefore delves into the driving forces of innovation. Analyzing and describing the driving forces that underlie the pattern of Swedish innovations is the main task of this thesis.

1.3 Research aim

Studying the case of the Swedish manufacturing industry 1970-2007, the primary aim of the current thesis is to examine how and to what extent innovations have been influenced by economic and other factors. Innovations are studied as the creative response to changes in the environment of firms, in industries and the aggregate economy. The richness in detail of the SWINNO database combined with the large number of observations also makes the new data suitable to both quantitative- and qualitative analyses. Since the study aims to answer both *to what extent* and *how* different factors have contributed to the development of innovations, the thesis employs both quantitative and qualitative methods. Questions of "whether" and "to what extent" will be primarily answered using quantitative descriptive statistics of innovation, whereas questions of "how" will be primarily answered using the qualitative information contained in the SWINNO database and historical analysis. All empirical chapters (4-7) are structured according to the principle of first answering questions of "whether" and "to what extent", followed by descriptions that answer questions of "how".

The aim of examining how and to what extent innovation activity has been influenced by economic and other factors is fulfilled by analysing macro-economic, industrial, inter-industrial and firm-level determinants of innovation. The following sets of questions are answered:

Q1 Did firms innovate during periods of crisis or growth? What patterns of innovation can be discerned during the period and how can they be explained? To what extent and how were innovations in the Swedish manufacturing industry the creative response to opportunities or problems?

Q2 What differences are there in patterns of innovation across industries? How has transformation pressure (e.g. technological opportunities, regulations, techno-economic problems or declining demand) shaped industry-level patterns of innovation activity?

Q3 To what extent and how has innovation activity been shaped by interdependencies between industries? What industries were related? To what extent and how has innovation activity been induced by technological imbalances in development blocks?

Q4 What firm-level factors drove the development of hardware electronics innovations?

For Q1-Q3 the entire manufacturing industry is studied. Firm-level determinants of innovations (Q4) are specifically studied for the hardware electronics industries.

1.4 Contributions

A starting point of this thesis is the observation that a systematic and holistic study of the determinants of innovation on the aggregate, industry and firm-levels of analysis may carry some way towards a better understanding of how innovation activity evolves as a response to changes in economic conditions. In contrast to previous research, this thesis examines simultaneously innovation as creative response on the aggregate, industry and firm-level for a single case, the Swedish manufacturing industry. This makes it possible to understand how driving forces operate on different levels to produce patterns of innovation and industrial transformation. Lack of consistent large scale data on innovation output has effectively made difficult the systematic empirical study of innovation activity and its driving forces on all levels of analysis and for longer periods of time. Studies on determinants of innovation has typically been focused to one level of explanation, from the study of samples of individual firms and entrepreneurs, to the study of technological systems of interrelated innovations and the determinants of innovation performance in whole economies. One stream of literature has stressed that innovation may be the response to changes in the economic conditions of firms (Penrose, 2009 [1959]; Cyert & March, 1963; for empirical research studying a wide range of factors, see e.g. Kleinknecht, 1996; Brouwer & Kleinknecht, 1999b; Greve, 2003b; Beers et al., 2008), or industries (Utterback, 1994; Breschi & Malerba, 1996; Nelson & Wolff, 1997; Marsili, 2001; Malerba, 2007). Innovation activity may also be understood as evolving as the response to opportunities and imbalances in 'technological systems' (Hughes, 1987; Carlsson & Stankiewicz, 1991) or 'development blocks' (Dahmén, 1950, 1991a). Broader changes in the economy, institutions, environmental regulations and social changes may spur and affect innovation activity as creative response (Grübler, 2002; Lerner, 2005; Moser, 2005). While, there are thus many perspectives on the causes and determinants of innovation, there is no established consensus picture of how or to what extent innovation activity is determined by economic factors. This study shows that patterns of innovation are largely and fundamentally shaped by both positive and negative factors on all these levels, producing patterns of innovation as evolving in waves or surges within sets of closely interdependent economic activities that are focused on the solution of problems or obstacles or the exploitation of new opportunities.

Moreover, this thesis studies both negative and positive factors simultaneously, allowing for the assessment of the relative contribution of several ostensibly opposed factors. Previous empirical research on aggregate patterns of innovation over time, in industries or in firms has tended to stress either positive factors or negative factors (there are recent exceptions in e.g. Greve, 2003b and Antonelli & Scellato, 2011). In particular, the debate of whether innovations are developed in periods of expansion or economic decline has taken such a character. Employing data on the sources of innovation, this thesis studies the influence of both positive and negative factors at any given datum. The thesis is able to find support for a particularly strong influence of negative factors during the crisis of the 1970s and that innovations driven by positive factors have been developed in two waves, culminating in 1983 and 2000, respectively. These findings indicate that positive and negative driving forces interact to produce patterns of innovation over time that appear to be of longer duration than the business cycles.

The thesis also contributes to the empirical research on Swedish innovation activity and its driving forces. Previous empirical research on Swedish innovation contains a great variety of empirical, methodological and theoretical vantage points. A strand of literature has described and studied industries or technological systems, e.g. the biotechnology system

(Stankiewicz, 1997; Backlund, Häggblad, et al., 2000), the automotive industry (Elsässer, 1995), the telecommunication industries (McKelvey et al., 1997; Mölleryd, 1999), electrical power (Kaijser, 1986; Schön, 1990), the pulp and paper industry (Bergquist, 2007; Söderholm, 2009; Bergquist & Söderholm, 2011), renewable energy technologies (Jacobsson, 2008) and the development block surrounding factory automation and computer technology (Carlsson, 1995; Eliasson, 2001). Another set of studies have focused on innovation cases, such as the development of Astra's pharmaceutical "Losec" (Eliasson & Eliasson, 1997), ASEA's HVDC technology (Fridlund, 1997), the Swedish High Speed Train project (Flink & Hultén, 1993) or Ericsson's AXE system (Vedin, 1992).

While many studies have described driving forces in particular parts of the Swedish innovation system, there is no previous study of the determinants of innovation in the Swedish manufacturing industry that employs systematic data on innovations and their driving forces. A particular aim of this thesis is to describe the "how" of innovation and to give qualitative examples that can be contrasted with the quantitative evidence of driving forces of innovation over time. By way of using both quantitative and qualitative sources, this thesis makes a contribution towards deepening and broadening our understanding of the particular driving forces and patterns of innovation that have characterized certain innovations and the Swedish industrial landscape as a whole. The impact of social, economic and environmental changes on innovation activity is described in general, among with particular driving forces in certain industries. Moreover, this thesis uses a novel methodology that combines qualitative and quantitative evidence to study how patterns of innovation are related to and evolving within development blocks of complementary activities. A major finding of the thesis lies in the observation of ten groups of industries in which innovation activity is characterized by close interdependencies. The patterns observed set focus on the inertia present in innovation activity. In some of these groups, for instance ICT industries, innovation has evolved by way of overcoming imbalances and exploiting new emerging opportunities. Other innovations, such as renewable energy technologies or electric cars, have emerged from structural imbalances of the oil-based production regime. Innovation activity in these groups has been characterized by overcoming obstacles.

1.5 Outline of the thesis

The thesis consists of eight chapters. Chapter 2 reviews theoretical perspectives on determinants of innovation and presents the analytical framework of the thesis. Chapter 3 presents the SWINNO database and the central variables and data used in the thesis. The analytical structure of the empirical chapters proceed from examining patterns of innovation on the macro-level (chapter 4) down to the firm-level (chapter 7). In chapter 4 the overall changes in the pattern of innovation over time are described and explained by way of an analysis of the positive and negative factors that has incited the development of innovations. Chapter 4 answers research question 1. In chapter 5 the differences in long term patterns of innovations are described and explained by an analysis of the sources of transformation pressure over time. Chapter 5 answers research question 2. Chapter 6 answers research question 3. In chapter 6 the concept of development blocks is employed to describe how innovation activity has been influenced by co-evolution and interdependencies across industries. This chapter employs a quantitative method to delineate groups of industries which were related in terms of flows of innovations, and uses these results to discuss how innovations have been influenced by technological imbalances arising in development blocks. Chapter 7 answers research question 2. In chapter 7 the firm-level determinants of innovation are analysed using the case of the hardware electronics industries. The chapter discusses the firm-level basis of the technology shift of Information and Communication Technologies (ICT), by studying patterns of entry of new firms and the role of firm-level performance among incumbent firms in spurring innovations.

Chapter 8 summarizes, discusses and synthesizes the previous findings and their implications for the view of innovation activity, industrial transformation and economic development.

1.6 Limitations of the study

The notion of innovation as creative response delimits the factors studied. As it were, the thesis studies economic or other factors to which firms intentionally *respond*. The current work thus primarily studies factors that can be said to have been directly contributing to or inciting the development of a certain innovation, such as a new technology, scientific advances or the recognition of a problem. Conversely, the focus being *response*, the current thesis is not primarily intended to study factors that have an intangible or indirect influence on innovations, such as institutional change, the knowledge base or human capital resources of firms, or the capability of firms to innovate. There is scope to study patterns of innovation across firms of different size (chapter 5). However, these patterns are not the main focus.

Other limitations pertain to the type of innovations and the set of industries studied. This thesis studies major and significant product innovations in the Swedish manufacturing industry during the period 1970-2007 (see chapter 3 for definitions). Accordingly, the results and the patterns observed cannot be taken to carry implications for the whole economy, all types of innovations or all types of creative response to changes in the environment of firms or industries. Other than innovations, responses to changes in the economic conditions of firms cannot be assessed in this work. The analysis of the industrial development of innovations is also constrained in its scope to innovations developed in the manufacturing industries with the notable exception of software innovations, which have been covered to a greater extent. This means that service innovations, and innovations developed in service industries, such as hotels and restaurants and health care services, are not covered in the current study.

2. Perspectives on the Economic Determinants of Innovation

2.1 Studying creative response

The principal aim of the current thesis is to examine how and to what extent innovations have been influenced by economic and other factors. As noted in the introductory chapter, a fundamental notion of endogenous innovation was supplied by Schumpeter's "The creative response in economic history" (1947) in distinguishing between 'adaptive response' and 'creative response'. The former denotes measures taken within the "existing practice" of an economy, industry or firm, whereas the latter denotes measures taken "outside of the range of existing practice" (Schumpeter, 1947, p. 150). The view of innovation as a creative response to changes in the condition of firms, industries or economies unites the theoretical accounts that make claims to lay bare the determinants of innovation activity. Schumpeter's notion of creative response is however also a fruitful point of departure in another sense. Schumpeter wrote that creative response rarely, if ever, is fully understood *ex ante*, i.e. cannot be predicted from "pre-existing facts". The 'how' of the mechanisms behind creative response "must therefore be investigated in each case" (Schumpeter, 1947, p. 150).

Schumpeter's perspective of innovation as creative response clarifies why the economic determinants of innovation are unlikely to be captured in a single economic model. Rather, the analysis of innovation as creative response may depart from the description of historically observed determinants of innovation. In this work this has been enabled by way of qualitative descriptions of the innovations contained in the SWINNO database (see chapter 3).

Such a broad approach however requires methodological and theoretical underpinnings. The first task of the present chapter is therefore to discuss the general points of departure of this thesis. The second is to review previous research on innovation as creative response. Previous literature has described a wide host of driving forces of innovation. The third task is to put forth an analytical framework that combines these insights at the firm, industry and aggregate level. The last task is to subsume these determinants of innovation into a classification of innovations in terms of their origin in economic factors that can be put to use in the subsequent chapters. It is suggested that one may approach the driving forces of innovations by a study of innovation as the response to *problems* and *opportunities*. In subsequent chapters, the categorization is used to organize the textual empirical evidence obtained from the SWINNO database.

2.2 General perspectives

Previous theoretical and empirical work has in various ways approached determinants of innovation. To a large extent, this research has focused in some way on a smaller set of determinants of innovation, on historical or general explanations or on some level of analysis or aggregation. A discussion of these aspects of economic research serves as the critical and constructive general points of departure of this thesis.

2.2.1 Positive and negative factors.

One may distinguish between two sets of theories of innovation as creative response: theories that have emphasized innovation as the response to negative or positive changes in economic conditions. The first have emphasized necessity as "the mother of invention". An early and influential contribution is found in Marx's concept of competition, describing how firms strive to attain extra profits through the adoption of new (labor-saving) machinery.[1] Thus capitalist competition is essentially technological competition in which agents are driven to find and adopt new technologies to gain competitive advantage. While the introduction of new machinery would create an advantage for the first mover, the introduction of new, cheaper and more

[1] Extra profits arose according to Marx from the competitive advantage through higher than average labor productivity. A detailed account is given in e.g. Carchedi (1991).

efficient techniques or machinery led to "moral depreciation", declines in the exchange value of capital, for its competitors. Firms with old machinery - whose paid historical cost was larger - must compete against lower prices and face therefore lower profitability (Marx, 1976 [1867], p. 528; Marx, 1992 [1885], pp. 250, 264). Marx (1992 [1885]) noted that a need to replace old machinery with new was particularly present during periods of economic crisis, especially if new technologies had been introduced.[2] Marx also emphasized the social content of technological development, and suggested a role of strikes and social conflict in inducing labor-saving machinery innovations.[3]

The Marxian mechanism between profitability and invention was taken up by John Hicks (1932) asserting that "a change in the relative prices of the factors of production is itself a spur to invention […] directed to economizing the use of a factor which has become relatively expensive" (Hicks, 1932, p. 124). This notion of factor price induced invention was elaborated by Rosenberg (1969) and in Binswanger et al. (1978) and has become a widespread tool in economic historical research (e.g. Habakkuk, 1962; David, 1975; Allen, 2009). The notion has been further developed as a theory of localized technological change. According to this theory, firms are local learners that respond to increases in factor prices by following the trodden path, i.e. by deepening the factor bias of technologies (David, 1975; Antonelli, 1995, 2006).[4]

The Marxian notion of technological competition was also absorbed by Schumpeter, in his *Capitalism, Socialism and Democracy* (1942), sug-

[2] "The means of labour are for the most part constantly revolutionized by the progress of industry. [...] competition forces the replacement of old means of labour by new ones before their natural demise, particularly when decisive revolutions have taken place. Catastrophe, crises, etc. are the principal causes that compel such premature renewals of equipment on a broad social scale" (Marx, 1992 [1885], p. 250).

[3] "In England, strikes have regularly given rise to the invention and application of new machines. Machines were, it may be said, the weapon employed by the capitalist to quell the revolt of specialized labour. The self-acting mule, the greatest invention of modern industry, put out of action the spinners who were in revolt" (Marx, 1975 [1847], pp. 154-155).

[4] Criticism was advanced from a neoclassical point-of-view towards the induced innovation approach. Salter (1966, p. 16) argued that "at competitive equilibrium each factor is being paid its marginal value product; therefore all factors are equally expensive to firms". This means that firms are primarily interested in reducing total costs rather than economizing on one specific factor, under competitive equilibrium. By contrast, David (1975), and later Antonelli (1995, 2006) have shown that induced innovation and factor-biased technological change follow from local learning, irreversibility, path dependence and switching costs of technologies.

gesting that competitive pressure propelled counter-measures. In Schumpeter's account the competitive mechanism was characterized by *creative destruction*.[5] Though Schumpeter was more reluctant to ascribe profits a prominent role (operating with a concept of profits in opposition to the classical economists), the notion of a link between competitive pressure, declining profitability and innovation activity has been absorbed in neo-Schumpeterian theory. In Nelson and Winter's evolutionary theory, declining profits of firms and market shares are for instance assumed to spur "search" for innovation (Nelson & Winter, 1982, pp. 214, 283-4). A seminal contribution was made by Cyert & March (1963) that proposed that problemistic search is spurred by unsatisfactory performance of the firm and provided a behavioral foundation (see section 2.3.4). Economic agents thus initiate search for solutions to problems encountered. Antonelli (1989) similarly proposed and found evidence for a notion of 'failure induced' innovation.

Studies emphasizing the role of positive factors in spurring innovation have pointed out demand and the supply of new technologies as primary incentives to innovation. The appearance of new technological opportunities were according to Schumpeter (1911) and Kirzner (1979) the main impulses to innovation. In this view entrepreneurial activity consists precisely in perceiving and grasping unnoticed opportunities. In various strands of research, appropriability conditions and opportunities have been advanced as determinants of innovation performance or R&D investment (Malerba & Orsenigo, 1993; Audretsch, 1995; Klevorick et al., 1995; Kleinknecht, 1996; Breschi et al., 2000; Shane, 2001; Malerba, 2002). Moreover, supply-push theories have emphasized the role of scientific discovery, the stock of knowledge (or human capital) and the productivity of researchers (see Arrow, 1962; Romer, 1990; Aghion & Howitt, 1992). Other scholars have cited changes in consumer preferences as causes of innovation Mowery & Rosenberg (1979), and general demand factors (for instance Schmookler, 1962; Geroski & Walters, 1995; Brouwer & Kleinknecht, 1999b). Schmookler (1962) found that invention (measured as patents) lagged behind economic indicators (sales and output). He argued that "expected profits from

[5]Through this concept Schumpeter emphasized the double nature of competition in shaping innovative behavior: The competition from "the new commodity, the new technology, the new source of supply…" Schumpeter wrote, is "competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives" (Schumpeter, 1942, p. 84).

invention, the ability to finance it, the number of potential inventors, and the dissatisfaction which invariably motivates it – are all likely to be positively associated with sales" (Schmookler, 1962, p. 18). The Schmooklerian hypothesis, and several empirical studies thus clearly propose a procyclical pattern of product innovation.

Recently synthetic theories have been proposed. Antonelli & Scellato (2011) and Antonelli (2011b), synthesizing the Keynesian, Schumpeterian and Marxian approaches have proposed a U-shaped relationship between profits and innovation. Firms are thus suggested to be likely to innovate in disequilibrium conditions, either during buoyant conditions or economic crisis. According to Antonelli (2011b, p. 20) "incentives and opportunities provides the basic mix of determinants to innovate." Similarly, writing in the traditions of the behavioral theory of the firm and the resource based view of the firm, Greve (2003a,b) and Pitelis (2007) have proposed that innovation may be seen as the response to negative performance feedback, but also enabled by 'excess' or 'slack' resources.

One may thus assume that both positive and negative factors have had an impact on innovation activity. This was the proposition made by Erik Dahmén (1950). A recurring theme in this thesis lies in his understanding of the process of industrial transformation as having "its center somewhere between two extreme situations", a positive situation characterized by opportunities, and a negative situation characterized by declining demand and a "strongly felt necessity to adjust and adapt" (Dahmén, 1991a, p. 138). Inspired by the Schumpeterian approach, Dahmén (1950, 1991a) coined the term 'transformation pressure' to describe the driving forces behind the industrial transformation process. A positive transformation pressure characterizes a situation dominated by opportunities, such as opportunities to increase production or advance or exploit new technologies. Conversely, a negative transformation pressure characterizes a situation dominated by declining profits or demand and a felt need for response (Dahmén, 1991a, 1993). These situations could call for countermeasures, adaptive or creative. Positive situations, characterized by new opportunities, would provide powerful incentives towards renewal and towards innovation as offensive countermeasures. Negative transformation pressure, for instance high input costs, could induce defensive countermeasures in cost reductions or organizational rationalization. Other types of negative transformation pressure could induce offensive countermeasures: "cases where innovations are induced by a destructive threat and thus would not otherwise have been forthcoming" (Dahmén, 1993, p. 23).[6]

While Dahmén was studying industrial transformation in a broader sense, I mean to suggest here that innovation activity can be understood using the same terminology. Thus innovation can be viewed as the creative response to changes in the economic environment that are either *positive* - such as new technological opportunities, increasing demand and increasing profitability - or *negative* - intensified competition, decreasing demand and decreasing profitability. Crucially, this understanding requires our empirical analysis to be able to, simultaneously, account for both positive and negative factors. This requirement is a first constructive methodological point of departure.

2.2.2 Historical and general mechanisms

Another dividing line among previous studies on the driving forces of innovation is the emphasis put on historical cases or causal mechanisms of broader generality. This study views these approaches as *complementary*. The Danish physicist Niels Bohr described the wave-particle dualism - the fact that material particles may behave as particles or waves under mutually exclusive situations - as a principle of complementarity (Bohr, 1937). Physicists have nowadays accepted that the reality of elementary particles encompasses mutually exclusive but complementary aspects. In a similar way, economic historians have long accepted that the study of historical processes encompass both the quantitative study of general mechanisms and qualitative description of unique events. One may say that the processes studied by historians are characterized both by the (more or less) general causal mechanisms along known paths, and *evolution*, the emergence of novelty and new historical situations in which cause and effect can only be established in retrospect (Georgescu-Roegen, 1971). The former is reversible locomotion, the latter is an irreversible process in historical time. The former is a quantitative affair, the latter a qualitative one. The two are

[6]The notion of "positive transformation pressure" can be replaced with "transformation opportunities" ("omvandlingsmöjligheter") as suggested by Erixon (1991, pp. 261-263), in order to reserve "pressure" for negative situations in which renewal is somehow coerced. Rightly so, "opportunity" is very often a suitable label for the positive factors that drive innovation activity. However, this thesis retains the notion of "positive transformation pressure" since positive situations are not only characterized by opportunities, but also require firms to overcome obstacles and problems to exploit the new opportunities. "Transformation pressure" is in this thesis understood as a strong inducement to transform, whether by the recognition of an opportunity or the risk of economic failure.

mutually exclusive because, as Georgescu-Roegen (1971, p. 97) expressed it, "quantity presupposes the abstraction of any qualitative variation". In this sense, quantitative measurement implies the assumption that the elements subsumed by it are equal in kind. Quantity begins where quality ends, as it were.

This is also the source of complementarity between Quantity and Quality. The latent annihilation of qualitative difference and change in quantitative methods is the source of several issues known to econometricians as "omitted variable bias" and "unobserved heterogeneity". Accounting for qualitative change over time and changes in the institutional, social and economic structure, pose similar challenges. These issues are often been advanced as weak points of quantitative techniques. Conversely, the study of qualitative examples cannot be properly assessed without some measure of their generalizability and importance in the greater scheme of things. This is why quantitative data is used to answer questions "whether" and "to what extent", while qualitative data may be used to answer questions of "how".

The view of this thesis is that the study of innovation as creative response may benefit from a systematized study of "whether" and "to what extent" followed by descriptions of "how" that aim to provide examples, nuance and substance to quantitative claims. As the reader may become aware, all empirical chapters (4-7) are structured accordingly.

Inherent in Schumpeter's distinction between creative and adaptive response is the view that creative response is fundamentally immersed in historical time. Creative response cannot be understood *ex ante* and even "changes social and economical situations for good", being therefore an essential element in the evolution of the economic system (Schumpeter, 1947, p. 150). Sharing Schumpeter's view, this thesis studies first and foremost historical mechanisms by the qualitative description of cases and the quantitative assessment of the importance of certain types of driving forces of innovation. However, one must note that this does not exclude the possibility that innovation as creative response in more generality is induced by certain pressures or certain types of historical situations. Any historical mechanisms observed may thus reflect more general relationships and mechanisms over time or across industries. The question of generality is therefore important, but it must also be treated as logically posterior to the observation of historical mechanisms. The focus of the empirical study lies therefore on the statistical and qualitative description of historically observed driving forces.

2.2.3 Macro or micro?

In analyzing the factors behind innovation as creative response, it is necessary to distinguish between factors in the immediate environment of firms from broader economic and societal factors.

A methodological issue at the core of social sciences is to what extent explanations should focus on individuals or aggregate, collective phenomena.[7] Some authors have emphasized micro-level explanations. The notion of methodological individualism was proposed by Schumpeter (1909) to denote an approach that starts from the individual phenomenon. This clearly does not deny the existence of complex phenomena and systems. However, in this view social (collective) phenomena are ultimately reducible to and expressible in terms of interactions among individuals (Arrow, 1994). Accordingly, explanations should be made in terms of individuals. For instance, in favour of a micro-oriented analysis that has become characteristic of the Austrian tradition Friedrich von Hayek (2008 [1931]) stated that "neither aggregates nor averages do act upon one another, and it will never be possible to establish necessary connections of cause and effect between them as we can between individual phenomena, individual prices etc" (Hayek, 2008 [1931], p. 200). In line with this view, the study of innovation as creative response may depart from the firm-level behaviors and firm-level factors that induce innovation.

On the other hand, economists and historians alike have emphasized the presence of interdependence and complexity in historical processes and in processes of technological change (Simon, 1962; Arthur, 1999; Antonelli, 2011b). Some such point of views are based on the notion of *emergence*, i.e. that the complex interaction between parts may result in new phenomena at a higher level. In brief: "The totality is not, as it were, a mere heap, but the whole is something besides the parts" (Aristotle *Met.* Book H, 1045a 8-10). Authors from Mill (2011 [1843]), Hayek (1945) to Arrow (1994) and Krugman (1996) writing more recently, attempt to reconcile methodological individualism with the notion of emergent phenomena, arguing that emergent phenomena can be expressed as the complex interaction between individ-

[7] I am only able to give a hint here of the long-standing theme in sociology and (continental) philosophy sometimes called the structure-agency problem, traced back to Émile Durkheim, Karl Marx, Talcott Parsons and Max Weber, with contributions by *inter alia* Louis Althusser, Margaret Archer, Roy Bhaskar, Pierre Bourdieu, Jacques Derrida, Michel Foucault and Anthony Giddens and writing more recently e.g. Karen Barad. This brief review can only discuss the most fundamental of viewpoints with immediate implications on economic historical method.

uals.[8] As it were, emergence is an unintended result of intended actions among individuals.[9] Others have considered emergent entities to be *irreducible* if the properties of the whole cannot be deduced *a priori* from the properties of the parts (e.g. physicists such as Polanyi, 1968; Nicolis & Prigogine, 1977, and economists as Georgescu-Roegen, 1971). Accordingly, several authors suggest that agency and micro-level phenomena are substantially both affecting and affected by systemic evolution. This understanding has been stressed in particular among authors writing in an evolutionary tradition (Arthur, 1999; Antonelli, 2011b). For students of industrial and technological development such as Rosenberg (1969), Gille (1978), Dahmén (1950, 1991a) or Hughes (1987), innovation activity is embedded in a system of interdependent actors, technologies, industries and institutions: "systèmes techniques", "technological systems" or "development blocks" that are emergent and substantially affect the conditions and inducement mechanisms of innovation (see section 2.3.3). These notions thus crucially suggest the study of the systemic and interdependent aspects of innovation and that failure to do so may imply a significant loss of information, also on the nature of creative response in the individual firm. From this point of view, it is desirable to study determinants of innovation activity in the context of broader societal, economic or technological processes where parts interact to form structures or systems.

This study takes the view that innovation as creative response involves both behavioral and systemic aspects - both agency and structure. The study assumes as its basic unit of analysis the individual innovation, and as the basic unit of agency the individual firm. However, the aim of the analysis is holistic in the sense that it aims to grasp the determinants of innovations as embedded in a system of interdependent parts, i.e. creative response as part of the broader societal, technological and economic development. It is then not only relevant to study the changes in the environment of innovating firms, but also how innovation activity has evolved within industries, how

[8] Mill pre-dated the introduction of the concept of methodological individualism. However, his stance on this matter was clear, as is evident from the following quote: "Men are not, when brought together, converted into another kind of substance, with different properties [...]. Human beings in society have no properties but those which are derived from, and may be resolved into, the laws of the nature of individual man" (Mill, 2011 [1843], p. 425).

[9] Arrow (1994, p. 3) for instance writes: "It is clear that the individualist perspective does play an essential role in understanding social phenomena. Particularly striking is the *emergent* nature of social phenomena, which may be very far from the motives of the individual interactions. It is a salutary check on any theory of the economy or any other part of society that the explanations make sense on the basis of the individuals involved."

innovation "co-evolves" between industries, and how innovation activity is affected by changes in the macroeconomic environment.

Therefore, as a third constructive point of departure, the analysis must be structured according to some organizing principle in which innovation as creative response is analysed separately at each level of analysis. As a basic division, this thesis distinguishes between the aggregate level, industry-level, inter-industry (i.e. the study of interdependencies across industries) and firm-level factors. In principle, this division corresponds to what is labelled by evolutionary economists (e.g. Dopfer et al., 2004) as macro-, meso- and micro. Meso-level refers to population behavior (i.e. the analysis of industries). This division is elaborated and substantiated as an organizing principle in section 2.4.1 below.

2.3 Perspectives on the determinants of innovation

Given the methodological points of departure sketched above, the following review discusses previous literature on determinants of innovations on the aggregate, industry, inter-industry and firm-level. The following review of theoretical perspectives starts off in the mostly macro-level debate on long waves and technological revolutions, i.e. the 'when' of innovation. It then proceeds from macro-level towards micro-level theories of economic determinants of innovation, dealing with industry-specific determinants of innovation, the role of interdependencies across industries and firms, and firm-level determinants of innovation.

2.3.1 Crisis, growth and technological revolutions - The 'when' of innovation

Is there a long-term regularity in innovation activity? Though this question is more far-reaching than the scope of this thesis, one of the motivations to the thesis lies in the debate on technological shifts and long wave phenomena and in the issues that have emerged through it. The issues raised by the long wave literature are first of all whether innovation activity clusters, i.e. is spread unevenly over time and across sectors. Second, the issue is whether innovation activity clusters during depressions or during periods of growth.

2.3.1.1 Innovation, cycles and long waves

Economists and historians alike have on the basis of regularities in the history of capitalism suggested the existence of a number of cyclic movements in economic activity. These have often been based on the study of the movements of specific economic variables. The inventory cycles of 3-4 years of duration (also called Kitchin cycles) and the investment cycle of 7-11 years of duration (also called Juglar cycles) are generally accepted. Kuznets (1930) proposed proposed cycles in fluctuation of prices, output and profitability of 15-25 years of duration, then called "secondary secular movements". They have subsequently been labelled "long swings or "Kuznets cycles". Such cycles have been found to pertain to population growth, international migration and construction and infrastructural investment (Kuznets, 1958; Abramovitz, 1961; Easterlin, 1966).

Innovation activity has in the literature typically been connected to longer cycles, also called long waves or Kondratiev waves. Though not the first to discuss recurrent phases of expansion and stagnation in industrial capitalism, the core framework for the theory of long waves was laid forth by the Russian economist Nicolai Kondratiev during the 1920s and 1930s. Kondratiev observed recurrent movements of approximately 45-60 years of duration, in prices, foreign trade, production and consumption, which he thought to be explained endogenously by the replacement of fixed capital. Kondratiev (1935) noted that such movements applied to technology as well: "during the recession of the long waves, an especially large number of important discoveries and inventions in the technique of production and communication are made, which, however, are usually applied on a large scale only at the beginning of the next long upswing" (Kondratiev, 1935, p. 111). The view that technological shifts take place by significant discontinuities, radical innovations that spur further innovation and investment activity is however more commonly attributed to Schumpeter's work on business cycles (Schumpeter, 1939). Cycles or long waves are viewed as intimately connected with clusters of innovations:

> "innovations do not remain isolated events, and are not evenly distributed in time, but […] on the contrary they tend to cluster, to come about in bunches, simply because first some, and then most, firms follow in the wake of successful innovation" (Schumpeter, 1939, p. 100).

This ‘band-wagon’ of innovations propels a period of prosperity, the expansionary phase of the cycle. Herein lies however, also the seed to the recession phase: as more firms introduce innovations entrepreneurial profits erode, and when technological opportunities are exhausted, investment decreases, prices fall and the rate of interest falls. Schumpeter recognized that, as the rate at which innovations are diffused may differ, several cycles may coexist. Schumpeter mentioned three: the Kithcin inventory cycle, the Juglar machinery investment cycle of 7-11 years, and the above-mentioned Kondratiev waves.

Schumpeter’s theory was famously criticized by Simon Kuznets (1940), among other things for not specifying a mechanism of why long waves would recur, why radical innovations would cluster or why they would recur with the time spans of the Juglar, Kitchin cycles and the Kondratiev waves. Interest in the theory of long waves waned during the post-war period. A renewed interest was stirred in the wake of the crisis of the 1970s. Contributions were made by Marxist (e.g. Mandel, 1964, 1975), Schumpeterian and other scholars elaborating on Kondratiev's contribution (e.g. Forrester, 1977; van Duijn, 1983). Gerhard Mensch (1979) came to take a key position, suggesting a 'depression-trigger' mechanism of basic innovations that explained the transition from depressive to expansive stages of the long wave. He observed that basic innovations were bunched in periods of depression, the 1820s and 1830s, the 1880s and the 1930s, and that during such periods the time-lapse between invention and innovation was shortened. Though supported by Kleinknecht (1981), this was a controversial claim. Clark et al. (1981) and Freeman et al. (1982) argued that the data used by Mensch stretched the evidence. Instead, they advanced a view closer to Schumpeter’s original view, namely that the bunching of innovations first of all "arises from the imitation and diffusion process and from the bunching of technically related families of innovations and inventions" (Clark et al., 1981, p. 321). Second, innovations were suggested to follow expectation of profits, thus more likely to take place no during depressions but during the recovery and boom. Mensch had "been looking at the wrong 'swarms'" (Freeman et al., 1982, pp. 66-67). Mandel similarly admitted that a long depression could stimulate search for new technologies, but argued that the wider diffusion of new technologies following depressions were conditioned by a recovery in the rate of profits and market expansion (Mandel, 1975; Mandel, 1995, pp. 112-113).[10]

[10]For instance: "for massive (as distinct from exploratory) innovations to occur, there must be simultaneously a sharp rise in the rate of profit and a significant enlargement of the

A great deal of the continued debate on innovation and long waves has revolved around the data on basic innovations and various non-parametric tests to account for the presence of clusters in time series data (Solomou, 1986; Kleinknecht, 1987, 1990; Silverberg & Lehnert, 1993; Silverberg, 2002; Kleinknecht & van der Panne, 2006; de Groot & Franses, 2009).To this date, the hypothesis that basic innovations are introduced in waves during periods of depression or during recovery and boom periods remains disputed (Silverberg, 2002; Kleinknecht & van der Panne, 2006).

The notion that waves of innovations follow upon major technological breakthroughs such as the integrated circuit (1971) has however obtained ample support. This notion is supported by descriptions of technology shift processes as General Purpose Technologies, Technological Revolutions and Development Blocks. The two latter concepts have maintained a close connection between recurring technology shifts and the generalization of the history of capitalism into successive periods of expansion and decline. Perez (1983) suggested the concept of 'technological styles' (also used and developed by Tylecote, 1992), later rephrased as "techno - economic paradigms", to describe the successive technological revolutions brought about by sets of radical innovations (Freeman & Louça, 2001; Perez, 2002). According to this line of research there has been five Kondratiev waves based on the diffusion of radical innovations (Freeman & Louça, 2001; Perez, 2002). In each wave there has been a set of "key inputs", such as microchips, produced by "motive industries" (Perez, 1983; Freeman & Perez, 1988). Moreover, Freeman & Louça (2001) and Perez (1983, 2002) connect the waves to particular branches of the economy that have implemented the key inputs, so-called "carrier" or "leading" branches. The proposed waves, major innovations involved and the leading branches are summarized in Table 2.1.

The above-mentioned theories of long waves and innovation have certain similarities to a chronology of Swedish economic development elaborating on the work of Johan Åkerman and Erik Dahmén. The task of this research tradition was to find "structural boundaries", i.e. boundaries between periods of structural stability (Åkerman, 1949; Krantz & Nilsson, 1978; Krantz & Schön, 1983; Ljungberg, 1990). In a manner similar to the analyses developed by e.g. Freeman & Louça (2001) and Perez (2002), this tradition has emphasized the long-term technological development in shaping economic development as a whole. From this Schumpeter-inspired per-

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market. No massive investment outlays in new technologies and new products will occur as long as prospective sales remain below a certain threshold" (Mandel, 1995, p. 111).

Table 2.1: Technological revolutions and Kondratiev waves.

Technological revolutions	Major innovation(s)	Leading branches
1. Water-powered mechanization of industry	Arkwright's Cromford mill (1771)	Cotton spinning, Iron products
2. Steam-powered mechanization of industry and transport	Liverpool - Manchester railway (1831)	Railways and railway equipment, steam engines, machine tools
3. Electrification of industry, transport, and the home	Carnegie's Bessemer steel rail plant (1875),	Electrical equipment, heavy engineering, steel products
4. Motorization of transport, civil economy and war	Ford's Highland Park assembly line (1913)	Automobiles, trucks, diesel engines, refineries
5. Computerization of entire economy	Intel microprocessor (1971)	Computers, software, telecommunications, biotechnology

Note: Based on Tylecote (1992), Perez (2002) and Freeman & Louça (2001).

spective, innovations emerge in sets of complementary activities, so-called *development blocks* (a concept which is dealt with in much greater depth below). Economic development is viewed as a fundamentally inert process, where structural imbalances are resolved by innovation activity. The development blocks create opportunities as well as techno-economic problems to solve for innovating firms. Crises arise in this framework in part due to the inertia and vested interests that emerge as a development block matures, opportunities wane and producers compete for contracting markets.

This research gives clear suggestions on the long-term pattern of innovation in the Swedish industry. Early in this research tradition, Krantz & Nilsson (1975) noted periods of structural stability that corresponded to Kuznets cycles or long swings of roughly 15-25 years of duration. In this perspective, Schön (1994, 1998, 2010) has proposed a historical generalization of the Swedish pattern of economic and technological development in two phases of roughly 20 years of duration based on two types of investment behavior of firms: investment towards renewal, or *transformation*, and investment towards efficiency, or *rationalization*.[11] Together these phases form a *structural cycle*. While the focus lies on industrial transformation,

[11] Schön (2010, pp. 19-20) gives a concise and accessible introduction in these terms.

Table 2.2: Development blocks and structural cycles in Sweden.

Development blocks	Structural crisis	Transformation crisis	Culmination crisis
Steam engine, railways	1845/1850	1865/1870	1875/1880
Dynamo, electric motor, electricity	1890/1895	1905/1910	1915/1920
Combustion engine, automotive vehicles	1930/1935	1950/1955	1960/1965
Micro-electronics, biotechnology	1975/1980	1990/1995	2000/2005

Note: Based on Schön (1994, 2010).

Schön (1998) stresses the interplay of industrial transformation with machinery investment cycles of 7-11 years of duration and long swings of infrastructural investment of 15-25 years of duration. The chronology of structural cycles and development blocks is summarized in Table 2.2.

The phases of the structural cycle are demarcated by three types of crisis. The *structural crises* have implied a drastic ending of periods of structural stability; they form the structural boundaries. Such were the crises of the late 1840s, the 1890s, the 1930s and the 1970s. In addition, the "Great Recession" of 2008 could be added to this list. These crises have often been the most far-reaching in the sense of affecting large parts of society, not only industry. Following the structural crises of the late 1840s, 1890s, 1930s and 1970s, new technologies, development blocks, have been formed around coal, steel and railways, electrification, the combustion engine and automotive vehicles, and micro-electronics. Following structural crises, new machinery equipment surrounding the new development blocks have historically taken roughly ten years, the length of a Juglar cycle, to achieve a breakthrough in the relative prices of machinery. Sharp falls in relative prices of machinery have been demonstrated in the first decade of the 20th century, the 1940s and the 1980s (Schön, 1998, 2006). These improvements have led to entry of new firms, rising investments in plants and residential constructions centered around the new expansion. During the transformation period focus lies on the renewed technological development and in this process domestic markets become central. However, during the course of the transformation period, profitability decreases, which slows down the propensity to invest. Competition stiffens and an investment decline follows.

Transformation crises have followed upon periods of renewed technological development and have according to Schön led to a strengthening of the orientation of growth in existing structures. Such was the crisis of the 1870s, the crisis of 1907/1908, the Korea recession (1951/1955) and the crisis of the 1990s. In the cases where such transformation crises were successful they have meant that economic growth in the new trajectories has been invigorated (Schön, 1994, pp. 64-6). During rationalization phases, structural transformation is invigorated by new forces of growth. A wider diffusion of new technologies has taken place and transformation is led in the direction of intensified rationalization and efficiency in the new technologies (Ibid., pp. 14-5). New investments take place based on a broader exploitation of the new forces of growth after the crisis. These may again spur innovations and investment in infrastructural projects, culminating some ten years later.

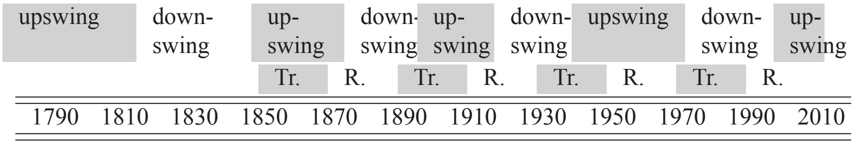
Culmination crises, the mildest type of crisis, have occurred at the culmination of transformation. Such were the crises of 1878/1879, 1920/22, 1961/63 and 2001/2003. These crises have led to phases of intensified competition and focus towards rationalization. The inertia that builds up during the rationalization phase has become an essential element in the structural crises that have followed.

In accordance with this periodization, Schön (2006) positions himself close to the perspective of Schumpeter, but also Clark et al. (1981) and Freeman et al. (1982), in arguing that the bunching of innovations, part of the diffusion process of core innovations, has taken place after the structural crisis, i.e. in the beginning of the transformation phase. The structural crises have contained both negative components and positive components. They are the crises of 'old industries' and technologies, while also enabling the emergence of new development blocks. The technological and economic development then follows a pattern in which investment is first directed towards overcoming obstacles and enabling the exploitation of new technologies. When the technology matures a wider diffusion is made possible, reaching final consumers. A wider diffusion of the core technologies may subsequently take place during the rationalization phase.

While there are similarities between these accounts, there are important differences in the dating of phases of Kondratiev waves viz-à-viz structural cycles. The illustration in Figure 2.1, an adaptation of a similar illustration in Edvinsson (2010a), shows the differences in the periodization of structural cycles and long waves.

These differences highlight the fact that Schön's historical generaliza-

Figure 2.1: Kondratiev waves (1780-2010) and structural cycles (1850-2010).



Note: Based on Freeman & Louça (2001) and Perez (2002), and Schön (1994, 2010). The periodization of Mandel (1975, 1995) is similar to the Kondratiev waves from the mid 1850s to the 1970s.

tion is based upon careful study of *transformation* by way of analysis of structural indicators (see Krantz & Nilsson, 1975; Schön, 1994, 1998). Long wave theorists have certainly relied on historical characterizations of technological change, but the focus in the periodization rather lies on economic growth - or, in the Marxist vein, profitability. Accordingly, long wave theorists have characterized the period between WWI and WWII as a downswing phase (1918 - 1940), while Schön on the other hand has argued that a phase of industrial transformation and technological expansion based on the combustion engine took place from the structural crisis of the 1930s. Similarly, the period from 1970 to 1990 is viewed as a long wave downswing in Perez (2002), but a period of transformation in Schön (2010). In the view of Schön (2006) mismatch between transformation and growth in this period is no mystery since aggregate economic effects of transformation has typically required the expansion of development blocks, the overcoming of economic and institutional obstacles and technological rationalization. Because of its closer focus on industrial transformation, the structural cycle model is more suitable to organize the analysis and describe the macroeconomic driving forces. This, and the fact that the account is based on the Swedish economic history, makes the structural cycle model a core point of reference and comparison in this work.

2.3.2 Industry patterns of innovation: Transformation pressure, competition and industry life cycles

The previously noted theories of technology shifts primarily describe macroeconomic patterns of innovations. It is broadly recognized however that patterns of innovation may differ greatly across industries and along the life cycle of an industry in terms of the driving forces of innovation and the types of firms that innovate. This section proposes a framework for the analysis of patterns of innovations across industries, based on the notion of positive and negative transformation pressure and related notions found in the literature on technological regimes and industry life cycles.

A common trait among many models of industrial patterns of innovation is that they are centered on the evolution of market structure and (technological) competition. Typically, one distinguishes between two modes of introduction of innovations, inspired by the conflicting contributions of Schumpeter's *Theorie der Wirtschaftlisches Entwicklung* 1911 and his later work *Capitalism, Socialism and Democracy* 1942. Market competition as a central mover to innovation was not at first emphasized by Schumpeter. In his early work, he saw as the main driving force of structural transformation the new entrepreneurs that challenge the prevailing structure of industries by introducing "new combinations". To Schumpeter, competitive patterns were characterized by some firms innovating, and some firms imitating or, as Fagerberg (2003) notes, improving on other innovations. This account, putting emphasis on entry of new firms and small firms, has been labelled "Schumpeter Mark I" (Nelson & Winter, 1982; Kamien, 1982). In this view, entry is characterized by technological ease. Schumpeter (1942) on the other hand took impression from the American pattern of innovation dominated by large scale firms with in-house R&D projects. Drawing on Joan Robinson's accounts of imperfect competition (Robinson, 1969 [1933]), Schumpeter held that "pure competition" had hardly ever existed (Schumpeter, 1942, pp. 79, 81) and drew attention to how monopolistic strategies dominate the business world, rendering price competition "ousted from its dominant position" (Schumpeter, 1942, p. 84). Competition is here limited partially by constraints conditioned by the nature of technology, high R&D-costs, but also by entry barriers as large firms have advantages in competence, access to finance and knowledge. This latter account has been labelled "Schumpeter Mark II".

These two types of competition have been taken up as the two central dimension of industry-level patterns of innovation. Other dimensions have been stressed as well. In an early contribution, Pavitt (1984) proposed a seminal taxonomy distinguishing between four types of sectoral patterns of innovation on the basis of firm size, knowledge base and the direction of innovation activity towards product design or cost cutting (see chapter 5).

Other authors have more recently developed the notion of technological regimes, based on the understanding of market structure and technological change as endogenous. The notion of technological regimes (e.g.

Malerba & Orsenigo, 1993; Breschi et al., 2000; Malerba, 2002) departs from the assumption that there are two determining factors of the intensity of innovation and the market structure: technological opportunities and appropriability conditions. In principle, a creative destruction pattern can be explained by high technological opportunities and low appropriability conditions. Conversely, high appropriability conditions and cumulative conditions may explain the emergence of a structure where only a few actors innovate.

Focusing on the historical evolution of industries, a vast literature has also pointed to the existence of regularities in the industrial patterns of competition and innovation over time (Abernathy & Utterback, 1978; Abernathy & Clark, 1985; Abernathy & Utterback, 1978; Gort & Klepper, 1982; Anderson & Tushman, 1990; Klepper, 1996; Utterback, 1994; Audretsch, 1995; Malerba et al., 1999; see Peltoniemi, 2011 for an overview). These viewpoints typically distinguish between different phases of industrial dynamics over the life cycle of industries. In terms of driving forces to innovations the ILC literature supposes that a transition takes place from performance maximizing technological to cost-minimizing strategies of firms during the course of a product's or industry's life cycle (Abernathy & Utterbach, 1975; Gort & Klepper, 1982). These are closely linked to the emergence of technological trajectories in industries, patterns of "normal" problem-solving activity (Dosi, 1982, pp. 148,152; Dosi, 1988, pp. 1127-8). The first phase can be labelled the "embryonic" phase. Most accounts view this as a phase of industrial emergence, where the entry of new firms and the development and introduction of a large number of product innovations are spurred by technological opportunities. The "growth" or "fluid" phase is characterized by a high number of firms, and a large number of production innovations spurred by technological opportunities. As the opportunities are exploited, uncertainty decreases on the product markets and a standardization of products takes place. The phase of "maturity" is therefore characterized by a stabilizing or declining number of competitors. Focus of industrial development shifts from product innovation to cost-minimizing and rationalizations favoring process innovation among larger firms. During the "decline" phase there is an shake out of firms and market concentration. While product innovations decline or stagnate in absolute numbers, interfirm competition or technological opportunities may incite product innovation among large incumbent firms. The main hypotheses derived from this literature are succinctly summarized in table 2.3.

It may be argued that the driving forces of innovation activity are only

Table 2.3: Stylized industry life cycles.

	Embryonic and Growth phases	Maturity and Decline
Product innovations	Large numbers and high variety	Dominant design and incremental innovations
Barriers to entry	Low	High
Technological trajectories	Performance maximizing	Cost minimizing
Technological opportunities	High	Low
Competition	Large numbers of small firms	Large firms, Oligopolies

Note: Based on Abernathy & Utterbach (1975), Gort & Klepper (1982) and Utterback (1994).

Table 2.4: Transformation pressures towards product innovation in the Dahménian typology.

	Market push	Market pull	Market pressure	Market contraction
Relative volumes	+	+	-	-
Relative price	-	+	-	+
Description	Competitive situation characterized by rapid technological innovation	Increased demand induced by other industries or rising input costs	Associated with competition from substitute products or imports	Typically associated with obsolete products
Transformation pressure	Product innovation	Process innovation and input substitution. Solve bottlenecks.	Find new markets for products. May involve product innovation in the adaptation of products to new uses.	Exit; find niche markets or develop high-tech products

Note: In part based on Dahmén (1950), Ljungberg (1990) and Svensson Henning (2009).

incompletely modelled along these lines. The broad perspective given by Dahmén suggests that an analysis of industrial patterns of innovation should proceed by distinguishing different types of *transformation pressures*, which encompass not only technological opportunities, but also problems and adversities stemming from a wide set of changes in the environment of firms. As stated earlier the process of economic transformation pressure is viewed as having its center between a situation of positive or negative transformation pressure. There are a broad range of sources of transformation pressure that may incite and shape innovative responses (Erixon, 1991).

These can in part be understood by way of a taxonomy of industrial economic performance. Dahmén distinguished between cases in which changes in demand are created by factors internal to industries, and cases in which such changes follow from factors external to industries. The industrial growth patterns can thus be classified. Dahmén (1950) made the distinction between advancing, stagnating and receding industries based on relative volume growth. For firms in advancing industries, characterized by growing volumes, two scenarios are possible. Market push ("marknadsutvidgning") refers to growth of demand due to causes internal to the industry, typically vigorous innovation activity. Market pull ("marknadssug") refers to growth of demand due to causes "external" to the industry (Dahmén, 1950, pp. 59-52; Ljungberg, 1990, pp. 72-77). Similarly, as regards stagnating and receding industries, the negative transformation pressure could be caused by factors internal to industries and cases in which it is caused by factors external to industries. Elaborating on this taxonomy, Ljungberg (1990) proposed that these two cases could be labelled "market contraction" ('marknadskrympning') and "market pressure" ('marknadstryck') respectively. Ljungberg furthermore proposed that these different cases correspond to patterns of relative volume growth and relative price growth.

The main types of transformation pressures across industries are summarized in the Table 2.4. The market push situation is then typically characterized by rapid technological change establishing a strong positive transformation pressure towards product innovation. In the market pull situation growth of demand takes place due to factors external to the industry. The demand growth may for instance be induced from other technologically advancing industries. The rise in relative prices may be caused due to rising input costs or techno-economic problems and production bottlenecks. These industries may thus be characterized by a transformation pressure towards input substitution, process innovation or problem-solving product innovation. Techno-economic problems may in the latter case be solved either by firms active in the industry or by supplier firms. Both of these cases may be related to embryonic and growth phases in the industry life-cycle.

The market pressure situation may be the expression of a structural crisis in industries, caused by external changes in demand, competition from substitute products or competition from other countries. When demand declines due to substitution, firms may find incentives and ways to direct their production towards other sectors. This in turn may involve finding solutions to apply industry knowledge in fundamentally new ways. This situation may be said to correspond to a maturity phase of the industry life cycle. A situation characterized by market contraction is finally a situation where, typically, the product is in the process of becoming obsolete but where due to imperfect competition prices may be kept high; a phase of "decline". Transformation pressure in these industries is expected to be directed towards developing niche products or towards market exit.

This summarizes hypotheses about how transformation pressure towards different types of product innovations are connected with the type of and, possibly phases of the industry-life cycle. On the one hand, market push industries are likely to have a large number of innovations, enabled by the exploitation of technological opportunities. In market pull industries, innovation activity may be motivated to resolve bottlenecks to the expansion of production. A negative transformation pressure may motivate innovations that solve obstacles to the attainment of rational production or lower costs. In industries characterized by market contraction, transformation pressure is established towards exit or finding niche market products.

2.3.3 Interdependencies and development blocks

The development of innovations and new technologies within industries may be studied in their own right. Historical studies however tell us that innovations come about in bunches and as parts of broader technology shifts in which technologies *co-evolve*. In this process innovations are induced by interdependencies. Several authors (Rosenberg, 1969; Gille, 1978; Hughes, 1987; Dahmén, 1950, 1991a) have stressed the systemic character of innovation activity and technological change, embodied in notions of: "systèmes techniques", "technological systems" or "development blocks". The development of new technologies interact and co-evolve with other technologies, institutions and actors (Nelson, 1994, 2001). An important task of this thesis is therefore to examine the interdependencies and interplay between technological advance in different industries - or, more specifically, how innovation activity is shaped by the development, or lack of development, in other industries.

On a fundamental level, co-evolution between parts of a system may be understood in both positive and negative terms. Positive interdependencies may arise due to increasing returns, positive externalities and path dependency in technology choices (Kaldor, 1981; David, 1985; Arthur, 1989, 1990, 1994). On the basis of positive externalities and increasing returns between agents of a system, structures of strongly interdependent agents, institutions and industries may emerge. On the other hand, precisely because of interdependencies, technological development typically requires the coming into place of other components. The lack of such components may become obstacles to further development and create *imbalances* that must be resolved. Such obstacles and imbalances may be technical, economic or social in character. Other obstacles may be systemic. As it were, path dependence and inert structures may create "lock-in" and inertia in technological systems that in themselves may provide obstacles to the development or diffusion of other technologies (Arthur, 1989, 1994). This has been argued to be the case as concerns renewable energy technologies (Unruh, 2000, 2002).

The dynamics of broader technology shifts as arising by way of a series of co-evolving technologies has been discussed in terms of general purpose technologies (Bresnahan & Trajtenberg, 1995; Helpman, 1998; Lipsey et al., 2005), technological styles (Perez, 1983; Tylecote, 1994) and techno-economic paradigms (Freeman & Louça, 2001; Perez, 2002), "Macro" versus "Micro" inventions (Mokyr, 1990; Allen, 2009), technological systems (Hughes, 1983, 1987) and development blocks (Dahmén, 1950, 1991a).

These concepts embody different views on the driving forces of innovation. The central difference between these perspectives is the varying emphasis put on positive and negative interrelations in the evolution of industries. In the view of General Purpose technologies, interdependencies between supply industries and user industries emerge when user sectors improve and enhance the key input (Bresnahan & Trajtenberg, 1995). Innovation may also be strongly induced by opportunities and problems generated in the activities of other firms or in user sectors. In numerous accounts (for instance Schmookler, 1966; van Duijn, 1983; von Hippel, 1988; DeBresson et al., 1996) innovations are considered demand-led, induced by customer-producer interactions and following patterns of demand for goods. As it were, existing interdependencies between firms, or sectors of economic activity, provide strong opportunities for innovation.

By contrast, other approaches have stressed the inertia in technological development. Despite a swift development of faster and better computers during the 1980s, the lack of productivity effects puzzled many economists. Robert Solow famously phrased this 'paradox' in the words "We can see the computers everywhere but in the productivity statistics" (cited in David, 1990). These other approaches have stressed that technology shifts evolve not only by the downstream improvement of new technologies, but by the solution of *imbalances* and techno-economic problems that appear throughout the life cycle of new technologies (Hughes, 1983; Dahmén, 1950, 1991a). The diffusion of new technologies simply takes time and requires the overcoming of numerous obstacles. These obstacles may be technical, economic, social and institutional in character. It has been claimed that this type of problems is one of the most important sources of innovation. Nathan Rosenberg (1969) noted that "The history of technology is replete with examples of the beneficent effects of this sort of imbalance as an inducement for further innovation" (Rosenberg, 1969, p. 10). A very similar view has been offered by Thomas Hughes' (1983; 1987) analysis of 'sociotechnical systems' that evolve through the emergence of 'salients' and 'reverse salients'. Reverse salients are backwards, underperforming components of the sociotechnical system, that hamper the development of the sociotechnical system as a whole. The situation is resolved by the identification and resolution of 'critical problems', problems that hinder the technological expansion. In the view of Hughes, "[i]nnumerable (probably most) inventions and technological development result from efforts to correct reverse salients" (Hughes, 1983, p. 80).

In this study, sets of interdependent innovations or activities, broad or narrow, will be called "development blocks" following the framework of (Dahmén, 1950, 1991a). This perspective allows both the analysis of positive and negative interdependencies between industries or firms. Development blocks are *complementary economic activities that are stimulated by innovations.* The central dynamics of a development block is provided by the fact that new technologies or innovations require investment and development efforts in other firms or industries. As it were, innovations create complementarities, or dependencies between firms, technologies, industries or institutions. In this process obstacles and imbalances appear that require the alignment of the technological frontier in other fields, or new innovations that solve technological problems. Development blocks are, put in a more involved manner, complementarities that appear sequentially as agents overcome obstacles or imbalances.[12]

The term *complementarity* may be developed further. A relation of complementarity may be understood as a rather specific type of positive interdependence between for instance factors of production, firms or industries. It may on a fundamental level be understood as a relation in which the combination of parts increases the value of both parts (also sometimes referred to as a positive externality).[13] However, a relation of complementarity may also be understood as an emergentist interdependence relation; a relation between parts that produces a totality, which is not only greater than the sum of the parts, but *novel*, meaning irreducible to the parts. A case in point is the co-evolution between computer hardware, software and data communication technologies which have mutually enhanced their capacities, enabling the World Wide Web.

The Dahménian approach stresses the inertia present in aligning components of development blocks. The lack of complementary factors may as it were hamper the development of other factors. Dahmén discussed, for instance, the unprofitability of railways during the late 19th century that were unprofitable until complementary investments in the railway network had been carried out (Dahmén, 1991 [1942], p. 30). This relation was referred to as *imbalances* or "structural tensions" Dahmén, 1950, p. 70-73; (Dahmén, 1991 [1942])).[14] Structural imbalances provide important incentives, or pressure, to innovate:

> "innovations in certain sectors and branches without any vision of a development block ex ante bring about 'structural tensions' which are observed ex post in the markets as an opportunity by actual and potential entrepreneurs. In such cases entrepreneurship consists of 'gap filling' within the framework of a development block ex post" (Dahmén, 1991b, p. 131).

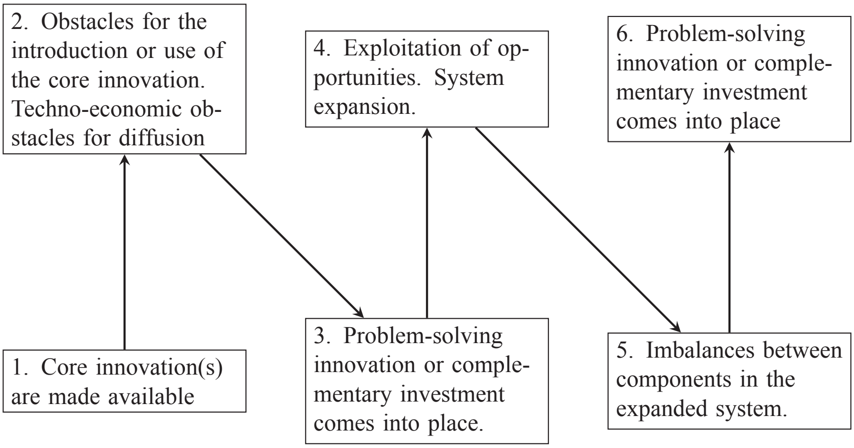
A strength in the concept of development blocks is that it may be viewed from a macro-, industry and even micro-level perspective, as sets of complementary activities that evolve by way of solving imbalances. The notion of development blocks has been found useful to describe broader sets

[12] Dahmén described the notion of a development block as "a sequence of complementarities which by way of a series of structural tensions, i.e., disequilibria, may result in a balanced situation" (Dahmén, 1991a, p. 138).

[13] Stieglitz & Heine (2007) gives a formal definition of complementarity as a relation in which the increase of one activity x increases the return r of the other y. The function can be expressed as $r = f(x, y)$ such that $\partial^2 r/\partial y \partial x > 0$.

[14] I will in the remainder of this work prefer imbalances over the latter term.

Figure 2.2: Schematic picture of the dynamics of innovation within development blocks over time.



Note: Based on Dahmén (1991a); Schön (1991, 2006). Compare also Hughes (1987).

of complementary factors, embodied in the three technological revolutions (Schön, 1991, 2006; Enflo et al., 2008; Schön, 2010). The evolution of these macro-level development blocks has been described as often following a characteristic pattern, of sequences of imbalances. Figure 2.2 summarizes the positive and negative factors that may emerge in a stylized evolution of a development block. In a first gestation phase, the fundamental technology has been known and possibly even in use, but techno-economic obstacles have remained to be solved before a technical breakthrough could be reached. For instance, the phenomenon of electricity was known long before its economic breakthrough, but it was in the 1890s that innovations of alternating current in a three-phase system solved the critical problem of transforming higher and lower voltage (Schön, 1990). Breakthroughs of new technologies are typically followed by a phase of innovations applying and improving on the core technology. Complementary innovations are necessary to enable the wider use and diffusion of the core technology. In particular, these followers enable a wider use of the core technology by lowering costs and improving the performance of the technology. When a price fall takes place, the technology may be diffused on a broader basis. Following this diffusion, the development blocks may expand. When the development block expands it may come to what may be referred to as a "network phase", in which the block encompasses a network (railroads, electricity grid, automotive transportation system or the data and telecommunication networks). Imbalances here may appear in the shape of imbalances in the alignment of components of the system. When the complementary investment and innovations come in place the evolution of the development block may enter into a new period of imbalances or regress to a more balanced situation of 'normal problem-solving' (Sahal, 1985; Dosi, 1982, 1988) activities of firms.

These accounts summarize how innovation activity, in different ways, may be induced by interdependencies or imbalances within development blocks.

2.3.4 Firm-level determinants of innovation. Entry, excess resources and negative performance feedback

Two main aspects of the micro-level driving forces of innovation have been stressed in previous research: the driving forces of entrant innovating firms and the determinants of innovation among incumbent firms. Schumpeter (1939) launched the idea of clusters of innovation and swarms of entrepreneurial activity. Since then the role played by entrant firms and entrepreneurship in innovation activity has spawned a large literature. In the view of Schumpeter (1911) and Kirzner (1979) entrepreneurial activity consists in perceiving and grasping unnoticed opportunities. In later contributions entrepreneurship is often defined in these terms (Wennekers & Thurik, 1999; Shane, 2003). Previous literature has accordingly emphasized technological opportunities at the industry-level and at the firm-level as predominant driving forces of innovative entry (e.g. Audretsch, 1995 and Shane, 2001).

A second line of literature has explored determinants of innovation among incumbent firms, in terms of incentives, opportunities, the size, and the capabilities of firms. Generic firm-level determinants of innovation, such as firm size (Kamien, 1982; Acs & Audretsch, 1990; Arvanitis, 1997, 2008), external finance or financial constraints(Hall, 2002; Mohnen et al., 2008; Tiwari et al., 2008; Ughetto, 2008; Brown et al., 2009) or demand (Brouwer & Kleinknecht, 1999b; Arvanitis, 2008) have been widely studied (see also Kleinknecht, 1996, Beers et al., 2008).

This study focuses on innovation as the creative response, to positive or negative factors. Innovations as spurred by positive or negative factors on the firm-level, could by all means be understood as cases of transformation pressure. However, the theory of transformation pressure is not intrinsically linked to a theory of firm behavior. There are more elaborate approaches that have aimed to explain innovation activity at the organizational level. As opposed to many models, these contributions stem from considerations of economic behavior under fundamental uncertainty. The topic of decision-making of agents under fundamental uncertainty (rather than risk) was explored by Knight (2006 [1921]) and Keynes (2008 [1921]). Major contributions were made in game theory (von Neumann & Morgenstern, 2007 [1944]) and other explorations on the subject (Alchian, 1950; Georgescu-Roegen, 1958; Shackle, 2013 [1970]). These contributions were focused on economic decisions, such as investment and strategies.

A seminal contribution to the theory of organizational behavior and innovation was made by Cyert & March 1963. The behavioral theory of the firm (BTF) emerged as a reaction to the strong and arguably unrealistic assumptions of the neoclassical theory of the firm. Instead of assumptions of (unbounded) rationality and utility maximization, the fundamental departing point of BTF lies in the concept of *bounded rationality*, originally introduced by Herbert Simon (1959; 1991). Contrary to the assumptions of neoclassical theory, firms and organizations are taken to operate under fundamental uncertainty (Alchian, 1950). They have (therefore) only limited information about the consequences of the available alternatives. Organizations may also stand before a wider range, or more complex set of alternatives than is possible to process. These conditions make the rational maximizing behavior of neoclassical theory unlikely. Instead, firms are assumed to pursue organizational goals, not necessarily restricted to the pursuance of profits and select the (first) alternative observed that meets those goals. Furthermore, firms find better alternatives by way of search. In the view of Cyert and March 1963 search was assumed to be problem-directed, i.e. stimulated by a specific problem. A problem could pertain to unsatisfactory technological or economic performance but also intra-firm conflicts between antagonistic groups (Pitelis, 2007). Accordingly, if the performance of a firm falls short of the goal set by the firm - the aspiration level - firms are likely to search for ways to achieve the goal through organizational, process or product innovation. Negative performance feedback, performance below the aspiration level, may thus be assumed to spur product innovation. In this vein of research, empirical studies have examined the extent to which product innovations and R&D result from problemistic search and "negative performance feedback" (Greve, 1996, 2003a,b).

The question is moreover how firms will conduct search as responses to negative performance feedback. Search behavior can be understood in terms of organizational and technological boundaries. Search can be carried out within or outside of the boundaries of the organization. Search can also be local or distant in relation to the technological knowledge base of the firm (Rosenkopf & Nerkar, 2001). Cyert and March assumed that search is "simple-minded", biased towards searching locally and within the firm initially. If local and internal search should fail, the firm is likely to expand the search process to include other firms, or consider distant search. March (1991) has proposed a similar distinction between exploitation and exploration. The former refers among other things to refinement, efficiency seeking and production. The latter to "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation" (March, 1991, p. 85). These concepts have become widely spread in literature on organizational adaptation and learning (e.g. Benner & Tushman, 2002; He & Wong, 2004; Katila & Ahuja, 2002; Greve, 2007). Studies of to what extent firms respond to adversity by way of exploration and exploitation in innovation activity are however few (Bolton, 1993; Greve, 2007).

Cyert & March (1963) however also discussed the lack of evidence at the time for problemistic search. Instead, they suggested that search also may be enabled by 'slack' resources, providing a source of funds for innovations that would not be approved in firms with a tight budget. Innovation could thus be more likely in organizations with unabsorbed and absorbed slack resources (Cyert & March, 1963, pp. 188-9). They suggested also that these innovations would not be problemistic, but rather improving the performance of the innovations. The difference between problem-oriented and slack innovation was suggested to be that the former would be directly linked to a problem and justifiable in the short run, while slack resources enables innovation processes that cannot be motivated by such problems. This suggestion is similar to the framework of Penrose (2009 [1959]) that proposed that innovation is *induced* by productive opportunities and excess resources. Penrose (2009 [1959], p. 58) discussed external and internal inducements to expansion. External inducements were:

> "changes in technology which call for production on a larger scale than before, discoveries and inventions the exploitation of which seems particularly promising or which opens up promising fields in supplementary directions, special opportunities to obtain a better market position or achieve some monopolistic advantage" (Penrose, 2009 [1959], p. 58).

However, at the level of the firm

> "internal inducements to expansion arise largely from the existence of a pool of unused productive services, resources and special knowledge, all of which will always be found within any firm" (Penrose, 2009 [1959], p. 59).

In the view of Penrose, the abundance of resources not only enables but *induces* the identification of new profitable ventures, and the exploitation of opportunities external to the firm. These concepts, relating to the grasping of technological opportunities, have later been developed and refined in the theory of absorptive capacity (Cohen & Levinthal, 1990) and the theory of dynamic capabilities (Teece & Pisano, 1994; Teece, 2007). The notion of dynamic capabilities stresses several aspects of firms' performance and ability to innovate, some of which can be approached statistically.[15] The current study is however only able to study firms' resources in a narrow sense as financial excess resources (see chapter 7).

2.4 Organizing principle and summary

2.4.1 From macro to micro. And back again

In the previous sections, the main approaches to the study of economic determinants to innovation at the economy, industry, inter-industry and firm-level have been reviewed. The aim now is to discuss a viable synthesis of the theories reviewed and to formulate a framework for the analysis of determinants of innovation. This in part makes it necessary to delineate a methodological approach which is potent to not only combine micro and macro-level analyses but to clearly state the interrelations between macro-phenomena and micro-phenomena. The challenge of marrying these perspectives is greatly aided by an organizing principle. The organizing principle employed here presupposes the identification of a set of agents, which may be further subdivided in principle, e.g. an organization. For each level of analysis there are two modes of explanation: 'within' and 'between'.

[15] For instance, Teece (2007) suggested several aspects of dynamic capabilities: the capability to seize opportunities, the capability to sense threats and opportunities and to enhance, protect and recombine the firm's intangible and tangible assets (Teece, 2007).

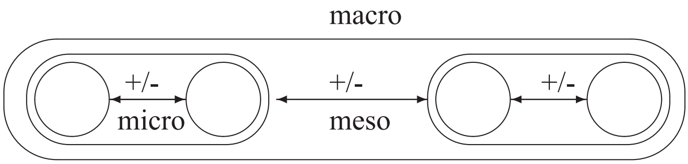
The development of an innovation can for instance be explained by factors within the organization or by the interaction between organizations.

Interactions between agents can be of different types. Evolutionary economists have sometimes drawn on standard biological classifications of the interactions between organisms (see e.g. Campbell 1984).[16] For the purposes of this study, I have, in Dahmén's spirit, distinguished between 'positive' and 'negative' interactions. Positive interactions are characterized by complementarity and opportunity. Negative interactions are characterized by rivalry and substitution. These interactions may be n-ary, i.e. take place between any number of agents. A multitude of complex interactions between agents may thus take place. As the number of actors involved increases, it becomes more sensible to analyze groups of agents. In our case we analyze industrial patterns of innovation. Similarly, we may understand industry-level patterns of innovation by the two modes of analysis 'within' and 'between'. Factors within industries that spur innovations may be labelled positive or negative transformation pressure in the vein of Dahmén. The between industry-level can be labelled 'inter-industry' factors. In the same manner we may distinguish between positive and negative driving forces in what Dahmén called development blocks. Dahmén suggested that innovation may be the response to techno-economic problems emerging in the course of the development of a development block and in a negative sense that "primary innovations may be creative in a double sense - both in their own right, and as stimulators of innovative countermeasures" (Dahmén, 1993, p. 23).

The macro-picture consists not of the sum of factors, but of the superimposition of these factors and their interactions. It is therefore sensible to start at the macro-level of analysis to obtain an overview of the macro-level overall factors that have contributed to innovation activity. This is done in chapter 4. Thereafter, the analysis decomposes industrial patterns of innovation (chapter 5) and analyses their interrelations in development blocks (chapter 6). In chapter 7, firm-level determinants of innovation are discussed. Since, however the complete picture consists of the superimposition of these factors, it cannot be given until factors at all levels have been discussed. This is the task of the final chapter in this thesis (chapter 8). In Figure 2.3 the proposition made here is illustrated.

[16]Mutualism is a plus-plus type of interaction - for instance cooperation, symbiosis and altruism - implying a mutual benefit of the organisms involved. Predation and parasitism are examples of plus-minus interactions. Competition is a minus-minus interaction.

Figure 2.3: Principles of aggregation.



Note: Firms (micro) interact positively or negatively within industries (meso), which in their turn are positively or negatively related. The macro-level expresses the superimposition of these interactions

2.4.2 Summary of derived propositions

The key claims identified in the literature are summarized below according to the organizing principle of distinguishing positive and negative factors on each level of analysis.

- *Macro:* At the macro-level, the debate has concerned the concentration of innovation activity to periods of economic growth responding to technological opportunities (Clark et al., 1981; Freeman et al., 1982; Geroski & Walters, 1995)) or periods of economic crisis (Mensch, 1979; Kleinknecht, 1987). A separate issue also concerns the possibility that innovation activity may be positively or negatively related to all cycles from the business cycle to Kondratiev waves. These issues are studied in chapter 4.

- *Within industries*: The reviewed industry-level accounts suggest that innovation activity is related to positive and negative transformation pressure. As it were, positive and negative transformation pressure is at force with various intensity across industries. On the one hand, advancing industries, characterized by rapidly increasing relative volumes, are likely to have a large and increasing number of innovations, enabled by the exploitation of technological opportunities. According to the ILC literature rapidly growing industries may be characterized by ample opportunities, ease of entry and large numbers of small firms (Klevorick et al., 1995). In other advancing industries, innovation activity may be motivated to resolve bottlenecks to the expansion of production. In stagnating or receding industries, a negative transformation pressure may motivate innovations that solve obstacles to the attainment of rational production or lower costs, or innovations that exploit remaining niche markets. These claims will be discussed in chapter 5.

- *Between industries:* Interdependencies between technologies and industries may be both a source of positive and negative transformation pressure. Two main types of inter-sectoral mechanisms have been proposed. Both positive and negative transformation pressure may induce the solution of techno-economic problems and the overcoming of imbalances (Rosenberg, 1969; Hughes, 1987; Dahmén, 1991a). These are thus not confined to either positive or negative factors. On the positive side however, as has been stressed by several authors, is also the exploitation of new opportunities and the improvement of new technologies downstream in the supply chain (Bresnahan & Trajtenberg, 1995; David, 1990). The Dahménian perspective of development blocks stresses that innovations evolve by way of both the overcoming of imbalances and opportunities. The extent to which either is the case is an empirical question.

- *Within firms:* Some accounts of firm-level determinants of innovation have stressed the role of both new entrepreneurs, or entrant firms (Schumpeter, 1911; Kirzner, 1979; Wennekers & Thurik, 1999; Shane, 2003). In these cases entrepreneurial activity is considered to be closely connected with the grasping of opportunities. Others have focused on the determinants of innovation among incumbent firms. On the positive side, excess resources, organizational slack and technological opportunities have been considered to be central factors (Cyert & March, 1963; Penrose, 2009 [1959]; Pitelis, 2007). On the other hand, negative performance feedback, e.g. declining profitability or failure, may be a significant inducement mechanism to problemistic search (Cyert & March, 1963; Nelson & Winter, 1982; Antonelli, 1989; Greve, 2003b). Other than slack search, and problemistic search, a third type of search has also been added: institutionalized search (March, 1981) to keep the firm at the competitive frontier. Chapter 7 examines the driving forces of innovation at the firm-level. The main issues in examining firm-level determinants of innovation appear to be two-fold. First, the question is to what extent innovation activity is driven by entrants or incumbents. Second, the question is to what extent incumbents have responded to negative performance feedback or are driven by slack or institutionalized search.

Finally, it must be acknowledged that a full account of determinants of innovation would explicitly also examine the *between-firms* level of analysis. Several accounts have stressed the role of user-customer interaction on the firm-level (see e.g. Lundvall, 1985; von Hippel, 1988), collaboration networks (see e.g. Ahuja, 2000), and on the negative side, the impact of inter-firm competition (see e.g. Kamien & Schwartz, 1972). Unfortunately, these dimensions cannot be directly studied in this thesis.

2.5 Operationalization

The key claims in the literature can be subsumed in a distinction between "opportunities" and "problems" as determinants of innovation as creative response. This distinction serves as a basic classification of the determinants of innovation that is put to use to examine the role of determinants of innovations

2.5.1 Problem-solving innovations: a synthesis

A central view in this thesis is that there is a common ground for many of the reviewed theories in the notion of innovation as a *problem-solving activity* suggested by Cyert & March (1963) and Dosi (1982, 1988). A uniting framework departs from the related notions of creative response and transformation pressure, and the micro-foundation provided by the behavioral theory of the firm. Firms are viewed as satisficing and boundedly rational agents, that initiate problemistic search in the face of unsatisfaction, adversity or a perceived threat (such as new competition, new legislation). Firms thus respond to transformation pressure by way of problemistic search. Thus, firms do not only respond to negative performance feedback (Greve, 2003a,b), but firms may respond to a host of factors that are not specific to the firm. This sets innovation as a *problem-solving* activity in focus.[17] In analysing innovation, we must thus understand the specific set

[17] Innovation as a problem-solving activity is taken to be broader than what is designated by Dosi's concept of technological trajectories, i.e. "the pattern of *'normal'* problem-solving

of problems that spurred the creative response in its proper historical setting. It is suggested in this work that by studying the types of problems that have generated search for new solutions, one may learn about the sources of transformation pressure. In this work, a classification of the problems is made to organize the empirical material and the discussion of problem-solving innovations.

Defining a problem as an obstacle to a certain criterion or goal, one may first distinguish between problems that are associated with a negative or a positive transformation pressure. This thesis distinguishes between three types of problems associated with a *negative* transformation pressure. *Induced innovations* are here understood as innovations that have been developed as a response to changes in factor prices, profits or to solve obstacles to the rational production and use of goods. This may for instance include the solution of a production or distribution bottleneck. The corresponding type of problem is labelled *economic*. Second, there are innovations that have responded to environmental regulations and broader environmental problems stemming from negative externalities (see Grübler, 2002 and Requate, 2005). These problems are labelled *environmental problems*. "Environmental problems" are in this work understood as synonymous with negative externalities, i.e. the negative effects of industrial production affecting a third party (other than the producer and consumer of a good). Third, one may distinguish innovations responding to demands pertaining to the work environment. These sets of problems have been labelled *organizational* problems, as they typically reflect intra-firm and broader social conflicts. In cases when problems pertain to issues of industrial waste or noise, a problem is considered environmental if the problems adversely affect a third party, whereas organizational problems are problems affecting staff within the boundaries of industrial production or a single firm.

By contrast, innovations responding to techno-economic obstacles to the exploitation of a new technology, product or market, are considered examples of creative response to a fundamentally *positive* transformation pressure. This interpretation is based on the notion that there is an underlying opportunity in this type of problem-solving activity. These problems will here be labelled as 'obstacles to the exploitation of new technologies'. When an abbreviation is needed "technological bottlenecks" will be used, which is taken to be a somewhat narrow concept referring specifically to techno-economic obstacles to the exploitation of a new technology, product, market or some other opportunity. As opposed to bottlenecks in the produc-

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activity" [emphasis added].

tion of goods (a production bottleneck), this refers thus to a bottleneck in the exploitation or development of a new technology. The classification of problem-solving innovations is shown in Table 2.5.

However, it is of the utmost importance to stress that the concept of 'imbalances' (Rosenberg, 1969; Dahmén, 1991a) should be understood as *transcending negative and positive situations*. This will become apparent in chapter 6. An imbalance is in this work understood as the negation of a relation of complementarity.[18] It is a situation in which a part, necessary for the accomplishment of an economic or technological goal, is missing or unsatisfactorily developed. A *technological* imbalance, is then understood as a situation in which there is an obstacle, technical in character, that needs to be solved for the attainment of a balanced situation. Such an obstacle is adequately described in the concept of *critical problems* by (Hughes, 1987). Thus, in this work the term "technological imbalance" is borrowed from Dahmén and Rosenberg to denote a relation between components or parts that requires the solution of critical problems for the attainment of a balanced situation.

All types of problems may thus in principle be technological imbalances. An innovation may eliminate obstacles, not only to the exploitation of a new technology, product or market, but also to the carrying out of some economic activity or the realization of some common goal among firms in an industry. An important dimension in the classification of problem-solving innovations therefore pertains to whether the innovation aims to resolve a 'technological imbalance', or not. As it were, technological imbalances lie at one end of the scale. At the other end of the scale are innovations that follow the 'normal' problem-solving trajectory of technologies (Sahal, 1985; Dosi, 1982, 1988), which may be taken to refer to a more balanced situation.

[18]Negation is here understood in a Sartrean sense, i.e. as an experienced absence or incompleteness. Negation, in Sartre's example, is the experience of Pierre's absence at the café where Sartre is expecting to meet him. The expectation of Pierre's presence makes this experience of absence a real event ("mon attente a fait *arriver* l'absence de Pierre comme un événement réel concernant ce café", see Sartre, 2008 [1943], p. 45). Similarly, I mean to say that an imbalance is an absence or incompleteness in a relation of complementarity. As Dahmén pointed out, this complementarity is sometimes anticipated (when actors envision the development block *ex ante*), sometimes not.

Table 2.5: Classification schedule of problem-solving innovations.

Problem area	*Examples*
1. *Economic* Techno-economic obstacles to the rational production of goods	Unprofitability, rising energy prices, irrational costs (e.g. material spill)
2. *Environmental:* Negative externalities	The handling of waste, replacement of environmentally harmful products
3. *Organizational:* Work-environment	Occupational noise, toxic welding gas
4. *Technological bottlenecks:* Techno-economic obstacles to the exploitation of a new technology, the production of a new good, or the opening of a new market	Capacity bottlenecks (e.g. insufficient capacity of switching circuits), Insufficient performance of technological components
5. *Miscellaneous:* Industry or firm-specific problems	Medical technical problems, idiosyncratic firm problems

2.5.2 Technological Opportunities

Second, it is widely recognized that innovations to a considerable extent stem from the discovery and exploitation of technological opportunities in industries, firms or within development blocks. In situations characterized by positive transformation pressure technological opportunities are ample and may spur the start-up of new firms or the entry of incumbent firms into new fields of production or to upgrade their old products.

Technological opportunities are in the current study taken to denote opportunities that stem from technological or scientific advances. Thus, the opportunities studied are quite distinct from other entrepreneurial opportunities, such as the observation of an unexploited market segment. The classification of technological opportunities depends however on the scope of the analysis. The thesis employs two definitions of technological opportunities. A narrow definition of opportunities includes only those innovations that *explicitly* cite opportunities as spurring the development of the innovation. This definition is used in chapters 5-7 to capture innovations that explicitly were enabled by the exploitation of technological opportunity. Two categories of the sources of technological opportunities are employed quantitatively in this thesis: origin in new technologies or materials and origin in scientific advances or academic research.

Chapter 4 studies the broader shifts in the structure and composition of innovations. This calls for a more inclusive definition of opportunities. Without explicitly citing technological opportunities as contributing to the initiation of development of the innovation, many innovations have exploited the fundamental technology shift surrounding microelectronics and computer technology in particular. Therefore, chapter 4 employs a broader definition, including not only innovations that explicitly have been driven by technological opportunities, but also innovations that have made use of microelectronics or computer technology in their core functions.

2.5.3 Summary: Positive and negative transformation pressure

The main concepts defined above may now be summarized to provide orientation in the structure of the following empirical analysis (chapters 4-7).

Negative transformation pressure is in this work straightforwardly understood to stem from three different types of problems: a) economic, b) environmental and c) organizational problems.

Positive transformation pressure is understood to stem from a) technological bottlenecks and b) opportunities. Technological bottlenecks are defined as obstacles to the exploitation of a *new* technology or the production of a *new* good. Technological opportunities may be understood in a narrow sense and a broad sense. The narrow definition of opportunities includes only those innovations that *explicitly* cite opportunities as spurring the development of the innovation. Among these, one may distinguish between opportunities stemming from scientific advances and other opportunities. However, to study the macro-pattern of the technology shifts that took place, a more inclusive definition is put to use. The broader definition of opportunities also includes innovations that make use of microelectronics in their core functions. The broad definition is employed in chapter 4. In the rest of the thesis the narrow definition is employed.

The notion of *technological imbalances* is put to use in chapter 6. Imbalances may characterize fundamentally negative situations as well as positive situations. A technological imbalance is defined as a situation in which there are technological obstacles, or "critical problems", to the attainment of a relation of complementarity. Imbalances thus is a comprehensive category that encompasses technological bottlenecks, environmental, social and economic problems.

3. Methods and Data[1]

This chapter introduces the SWINNO database, the underlying methodology and the data sources used in this thesis. In sections 3.1.-3.3., the Literature based innovation output methodology is introduced along with the operational definition of innovation used in the construction of the database. Section 3.4. introduces the most fundamental variables used in the thesis as regards the innovation process, industry classifications, and data on the innovating firm. Sections 3.5-3.6 introduce the variables constructed by the author of this thesis and other data sources employed. A discussion of methodological concerns and critical assessment of the SWINNO database is also found in Appendix A.

3.1 SWINNO - Swedish innovations

SWINNO (Swedish innovation) is a new database constructed by Karolin Sjöö and the author of this thesis.

SWINNO contains extensive information about single product innovations commercialized by Swedish manufacturing firms between 1970 and 2007. SWINNO is an unprecedented source of information about Swedish innovation in combining depth and width; the database contains detailed information about more than 4000 innovations, to which come more than 500 inventions or projects that had, so far (by end of 2007), not been commercialized. The new data gives hitherto unparalleled opportunities to picture technological and industrial developments in the Swedish manufacturing sector over an eventful thirty-eight year period. The richness in detail combined with the large number of observations makes the new data suitable

[1]This chapter is in part based on or identical to Sjöö et al. (2014). Sections 3.5-3.6 pertain specifically to this thesis.

to both quantitative- and qualitative analyses. SWINNO is modelled after the Finnish SFINNO database (Palmberg, 2004; Saarinen, 2005; Van Der Have forthcoming, Rilla forthcoming). SFINNO contains some 3400 innovations commercialized by Finnish firms between 1985 and 2009. In addition to SFINNO there is another Finnish database; H-Inno which contains 1593 observations of innovations commercialized between 1945 and 1984.

3.2 Innovation indicators and measurements

Back in 1962 Kuznets noted that innovation is an elusive phenomenon that we had better understand if answers were sought to questions about the economic role of technological change Kuznets (1962). According to Patel & Pavitt (1997, p. 143) "[t]echnological artifacts, and the organizational [sic] and economic worlds in which they are embedded, are *complex* and *everchanging*: they each comprise so many variables and interactions that it is impossible to fully model, predict and control their behavior through explicit and codified theories and guidelines". The inherent difficulties in metering innovation together with the step-motherly treatment thereof in neoclassical economics have spurred a sizeable group of scholars to try breaking up the "black box" of innovation (Archibugi, 1988; Rosenberg, 1982). The ardent wish to understand innovation has made researchers approach various dimensions of the phenomenon. Today a set of science-, technology-, and innovation indicators are available to innovation scholars. Kleinknecht and colleagues 2002 conclude that depending on what indicator is chosen, researchers may arrive at very different conclusions. The indicators reviewed here can be characterized along two lines; whether they are input-, output-, or intermediary output indicators and whether they are object- or subject based.

3.2.1 The innovation process: what goes in and what comes out

Research and development (R&D) is by far the most often used innovation indicator. The heading incorporates both the production- and application of new knowledge (OECD, 2002). It is commonly measured as expenditures or the share of personnel or hours worked that are devoted to R&D activities (Smith, 2005). Its popularity can be explained by availability, long time series (going back to the early 1960s when OECD started to systematically collect data see the present Frascati Manual for a brief history (OECD, 2002), opportunities for various comparisons, and its' increasing sophistication (van der Panne, 2007). Recognizing that not all expenditures related to innovation are classified as traditional R&D (and therefore go unnoticed), Brouwer & Kleinknecht (1997) sought to estimate total innovation expenditures. As measurements of innovation, R&D or total innovation expenditures are classified as input indicators and only proxy measures of actual innovation, if the latter is defined strictly as a commercialized good or service.

Patents are another widely used indicator of innovation (see Nagaoka et al., 2010; Archibugi, 1992 or Griliches, 1990 for an overview). The patent system addresses the disincentive for firms and individuals to engage in the development of new technologies stemming from the public good nature of knowledge through guaranteeing the developer thereof sole proprietorship (monopoly) for an extensive period of time. In doing so, the patent system mends the problem of underinvestment in knowledge. The benefits of patent data include easy access and a vast number of observations. Patent data and patent citations enable rich information on the cumulative flow of knowledge in the economy, and the characteristics of technologies. What is more, the fact that someone found it worthwhile to spend their money and time to apply for a patent, outwait the decision of a patent office and risk the latter's disapproval indicates some economic and/or technological significance (Kuznets, 1962, p. 36). While a patent is an output of a development process it first and foremost measures invention rather than a Schumpeterian innovation (Griliches, 1990; Basberg, 1987). Not all patented inventions will be commercialized and all innovations will not be patented (Kleinknecht et al., 2002; Brouwer & Kleinknecht, 1999a; Arundel & Kabla, 1998; Pianta & Archibugi, 1996; Arora et al., 2004). Patents are thus classified as an intermediary innovation output indicator.

Depending on the research question, the above-mentioned innovation indicators may be sufficient and preferred; R&D feeds innovation and patents result from development processes. Still, a linear relationship, in which actual innovation can be traced by help of R&D and patents is hard to pin down. The same remark has been made regarding other innovation proxies such as licenses, scientific publications, trademarks, and utility models (Mendonça et al., 2004; Beneito, 2006; Nelson, 2009). As measurements of actual innovation neither of the above fill the bill.

Imperfections aside, R&D and patents are the most often used innovation indicators today. However, their prominence was contested early on. The 1960s and 1970s saw an intense debate and various measurement approaches. The discussion revolved around the benefits of input- and various output approaches and engaged OECD as well as national authorities (Godin, 2002). Suggested output approaches aimed at the very products of innovation processes through the identification, counting, and following up on commercialized technological innovations.

The British Association for the Advancement of Science was among the first to engage in the systematic collection of innovation output data in the late 1950s (see Carter & Williams, 1957, 1958 for reports). The U.S. National Science Foundation and various academic institutions followed suit in the 1960s (see Myers & Marquis, 1969 for a report on the NSF project; see Godin, 2002 for an overview of early studies). Output studies use various methods of measurement; interviews (Myers & Marquis, 1969), the opinions of experts (Gellman Research Associates 1976; Townsend et al., 1981), and the screening of trade journals (Gellman Research Associates 1982), sometimes in combination (Edwards & Gordon, 1987).

Through innovation surveys firms are asked for example to estimate their innovation output and the sales share of this output (Kleinknecht et al., 2002). Some first surveys were conducted in the 1950s and 1960s but it was not until the 1970s that surveys gained momentum as the preferred method of output measurement in OECD, the U.S. National Science Foundation and other influential organizations (Mairesse & Mohnen, 2010; Godin, 2002). Since then, surveys are becoming the all the more dominant source of information about innovations (Smith, 2005; Sauermann & Roach, 2013). Especially, the EUROSTAT-managed Community Innovation Survey (CIS) has, since its first launch in 1993, provided ample opportunities to analyze topics related to various phases of the innovation process. Other ways to capture innovation output (e.g. expert-opinion and literature searches) have pursued lives in the shadow of the dominating surveys (Kleinknecht & Bain, 1993). The pros and cons of surveys and various innovation count approaches are discussed in the next section.

3.2.2 Output counts: subjects or objects

Innovation output indicators can be classified as either subject- or object based (OECD 1997; Archibugi, 1988). Subject-based indicators approach innovation output from the point of view of the innovating agent; a firm or a single entrepreneur. Surveys are by far the most often used method to tap information about firms' innovation produce. Object-based indicators probe various characteristics of innovation objects themselves. The act of identifying innovation objects bypass information available from managers or other consignors of innovation. In the history of object-based indicators there are primarily two sources that have been used; industry experts and literature.

Both subject- and object based indicators have benefits and disadvantages. Subject-based indicators may answer questions related to innovation activities in firms independent on whether they have been successful in innovation or not. Innovation objects may be observed without the perceptual blur of self-reporting R&D managers. The two following sections discuss the pros and cons of the two approaches.

3.2.2.1 Voices of innovating subjects

There are obvious advantages in going directly to the source of innovation; there are limitless options regarding what to ask and as long as questions are fine-tuned and guarantee trade secrets to be kept there are good prospects to obtain useful answers. Surveys make detailed micro-level data available to researchers and enable benchmarking, monitoring, and analyzing of innovation processes- and performance. In later years surveys have become the all the more dominating source of data on innovation and innovation activities.

While first hand information on innovation processes- and outcomes is attractive it is not flawless. The results from surveys are afflicted with problems of cognitive biases. Such biases are related to the situation that individuals, often managers with high-level responsibilities, are asked to make performance assessments; survey answers are thus perceptual- rather than objective measures. There is an extensive literature on the problems related to self-reporting (see e.g. Donaldson & Grant-Vallone, 2002; Stone et al., 2000 or Podsakoff & Organ, 1986). One major issue, widely observed in the literature, is that respondents tend to answer in a way that is socially desirable or make them appear in a favorable light (Moorman & Podsakoff, 1992; Zerbe & Paulhus, 1987). In a sense, asking an R&D manager to assess the output of R&D efforts is a way to ask this person to evaluate his or her own work.

Being in an exposed position, managers may be prone to exaggerate results and the innovativeness of firms may thus be overestimated. An enclosed definition of innovation (or other items for that matter) is commonplace but the likelihood for over-reporting may be augmented by the fact that respondents are left with the task of assessing whether their own new products comply with the definition or not (Mairesse & Mohnen, 2010; Landy & Farr, 1980). An illustration of the difficulties in retrieving valid items is Kleinknecht (1993) who reports about a situation in which twenty firms sent back two filled out survey forms. While not being intended by the researchers, two respondents in the same firm had filled out the form unknowingly of each other. The numbers of innovation reported (by representatives of the same firm) in the forms differed to an extent that the researchers found no other solution but to drop that particular question in subsequent surveys.

Another problematic issue is that survey answers are highly sensitive to what questions are being asked and how they are asked (Schwarz, 1999; Spector, 1994). Poor construct validity will have significant influence on what conclusions that can be inferred. Thus, when the share of innovation studies based on for example CIS increases, a problem of common method variance bias may impair our knowledge about innovation (Podsakoff et al., 2003; Spector, 2006). An increasing use of innovation surveys must thus be coupled with continuous discussions about the validity of constructs. Other issues that influence the quality of survey data are varying response rate and response bias (Sauermann & Roach, 2013).

3.2.2.2 Messages from innovation objects

Object-based innovation output approaches were developed to shed light on the relation between new technologies, industry dynamics, and economic development by counting individual innovations (Pianta & Archibugi, 1996). In a second step the method inquires into the characteristics of the firms to which the identified innovations are assigned. The first-hand focus on the output objects of innovation processes has been argued to enable a measure of *innovation proper* (Godin, 2002). Different sources have been used to identify innovation objects. The developed approaches can be divided into two classes; those based on the opinions of industry experts and those based on the surveying of some kind of literature. The latter approach has been referred to as a literature-based innovation output method (henceforth LBIO) (Kleinknecht & Bain, 1993). The expert-opinion method is self-explanatory; industry experts are asked to list innovations and name the developing firms (Townsend et al., 1981). The LBIO method uses primarily industry periodicals but researchers may also rely on other historical sources. Both the expert-opinion- and the LBIO-method are dependent on the assessments of one or more individuals (experts, editors, or authors); an innovation that goes unnoticed by any of these individuals will not end up in the data. Object-based methods are thus, much as subject-based methods, relying on perceptual judgements. Still, object-based methods escape the drawbacks of self-reporting since sources are independent. The filtering of information through the perception and assessments of individuals may however result in a "significance" bias in the data if only innovations with a certain level of significance are reported (Makkonen & van der Have, 2013; Edwards & Gordon, 1987, pp. 14-15)

Objects, or count, approaches go back a long time. In 1972 Langrish & Langrish (1972) produced an exhaustive coverage of 84 innovations that had been given the Queens Award for technological innovation in 1966 and 1967. Detailed case studies of each individual innovation were undertaken. Gellman Research Associates (1976) built one of the first longitudinal innovation output databases. 500 innovations commercialized in several countries between 1953 and 1973 were identified. The innovations counted were "the most significant new industrial products and processes, in terms of their technological importance and economic and social impact (NSF, p. 100). The innovations in this National Science Foundation-funded (U.S.) project were identified by help of an international panel of experts.

The Gellman Research Associates put together another output-based data set some years later (1982), this time based on the screening of fourteen U.S. trade journals published between 1970 and 1979. All in all they identified 590 innovations. The Science and Policy Research Unit at the University of Sussex undertook the thus far most ambitious effort when researchers during a fifteen-year-long period built an expert-opinion-based dataset with information on 4378 innovations commercialized between 1945 and 1983 (Pavitt et al., 1987; Townsend et al., 1981). The Futures Group, commissioned by the U.S. Small Business Administration put together a dataset with 8074 innovations (of which 4476 originating from manufacturing firms) commercialized in 1982 (Edwards & Gordon, 1987; Acs & Audretsch, 1990). The Futures Group screened over 100 trade journals in search for innovations.

A number of object-based studies using primarily the LBIO-method were conducted during the 1990s. A volume edited by Kleinknecht & Bain (1993) collect studies on Austria (Fleissner et al., 1993), Ireland (Cogan, 1993), the Netherlands (Kleinknecht et al., 1993), and the U.S. citepacs1993. Later, studies on the UK (Coombs et al., 1996), Italy (Santarelli & Piergiovanni, 1996), Spain Flor & Oltra (2004), and Finland (Palmberg, 2003;

Saarinen, 2005; Van Der Have forthcoming; Rilla forthcoming) have been published. A recent study on Schumpeterian swarms of breakthrough inventions sourced data from the journal "Research & Development", which since 1963 reward hundred innovations that stand out in terms of technological significance (Fontana et al., 2012).

There are also studies on single industries and sectors; shipbuilding (Greve, 2003a), logistics (Grawe, 2009), and public service organizations (Walker et al., 2002). Makkonen & van der Have (2013) and Acs et al. (2002) discuss and use innovation counts to benchmark regional innovation performance. The only LBIO database that is continuously updated is, to our knowledge, the Finnish SFINNO (Suomi Finland Innovations) database.

To date, there is only one major object-based dataset with observations of Swedish innovations. In the early 1980s Torkel Wallmark and Douglas McQueen at Chalmers University of Technology put together a dataset of the 100 most important Swedish innovations between 1945 and 1980 by screening annual reports of the Royal Swedish Academy of Engineering Sciences (IVA). The innovations identified by Wallmark and McQueen are, in the words of the authors: "the cream of the crop". The authors applied an ex post requirement of economic importance, they filtered innovations that by the year 1980 accounted for a minimum of $3.5 million of the innovating firm's turnover.[2] In 1979 the 100 innovations accounted for about 5 percent of value added in Swedish industry and 2.5 percent of GNP (Granstrand & Alänge, 1995). As a result of the criterion set for inclusion, Wallmark and McQueen's rate of innovation decreases towards the end of the period. With regard to the level of technological significance, Wallmark and McQueen only consider patented innovations. To a large extent, the patent criterion excludes process and system innovations from being observed as such innovations are not patented as regularly as product innovation (Granstrand & Alänge, 1995). Furthermore, the Wallmark McQueen data does not consider military innovations. The dataset differs from SWINNO not only in terms of the number of observations, but also in several other aspects, not least the inclusion criterion. While the Wallmark McQueen data only represent innovations that have had a true impact, SWINNO captures every type of innovation output that was at one point in time assessed to have updated or modified the structure of the innovating firm's product portfolio to a significant extent. In addition to the Wallmark McQueen data, there is a Swedish Institute publication authored by Kjell Sedig (under the category

[2]In prices of 1980 (Wallmark & McQueen, 1988, 1991).

of 'popular science') covering 59 major Swedish innovations between 1900 and 2002 (Sedig & Olson, 2002).

3.3 Building the SWINNO database

The SWINNO database was constructed using the literature-based innovation output (LBIO) approach briefly explained above. This section describes and discusses the method and choices that were made in the process of collecting and handling the data. It also raises some methodological concerns and discusses the validity of the data. A discussion of methodological concerns and critical assessment of the SWINNO database is also found in Appendix A.

3.3.1 Data and capta

Working with primary sources takes both time and effort. The American economic historian Deirdre McCloskey has made the remark that the output of such work should be labelled capta (Latin for things taken or seized) rather than data (Latin for things given) (McCloskey, 1986). The SWINNO data was not given, but very much taken. Putting together a LBIO database is an endeavor which is particularly labor intensive. Several years were spent reading trade journals alone. In total, thirty-eight volumes (1970 - 2007) of fifteen different journals were screened, the number of issues exceeds 8600. The majority of journals were published monthly, with some issued on a bi-weekly and others on a weekly basis. A non-negligible share of these was read on more than one occasion. Eventually, information from over 6000 articles was recorded and categorized but the number of articles read naturally exceeds that number by far.[3]

3.3.2 Selecting journals

[3]More than a thousand innovations were mentioned in more than one journal article, thus the number of articles exceeds the number of different innovations.

Table 3.1: All included journals, their changes of names, orientation and main technology focus.

Journal	Orientation	Main focus
1. Automation 1973-2007	General	Automation- and general production process technology, e.g. robots, industrial surveillance systems and computers.
2. Ny Teknik 1970-2007	General	Electrotechnology, chemistry, mining, mechanics, shipbuilding, automobile- and power technology, construction of roads, houses and hydronomy, automation technology.
3. Verkstäderna 1970-2007	General	Machinery and equipment for the production of various products. Products from engineering industries.
4. Modern Elektronik 1970-1992 » Elteknik 1970-1992 » Elektroniktidningen 1992-2007	Specialized	Electronic components and equipment, telecommunication equipment.
5. Kemisk Tidskrift 1970-1992 » Kemivärlden 1992 » Kemisk Tidskrift 1992-1999 » Kemivärlden 1999-2007	Specialized	Chemical- and pharmaceutical products, machinery and equipment for the production of chemicals and pharmaceuticals.
6. Livsmedelsteknik 1970-2003 » Livsmedel i Fokus 2003-2007	Specialized	Foodstuff, machinery and equipment for the production of foodstuff, packaging machines- and products
7. Plastforum 1970-1977 » Plastforum Scandinavia 1977-1992 » Plastforum 1992-2000 » Plastforum Nordica 2000-2003 » Plastforum 2003-2007	Specialized	Qualities of plastics and rubber, plastic- and rubber products. Machines for the production of plastics and rubber.
8. Sågverken, Trävaruindustrien 1970-1974 » Sågverken 1974-1999 » NTT Såg and NTT Trä 1999-2002 » NTT Såg & Trä 2002-2007	Specialized	Wood and wood products, wood cutting machines and similar.
9. VVS 1970-1982 » VVS & Energi 1983-1989 » Energi & Miljö 1990-2007	Specialized	Ventilation systems, equipment for the installation of pipes and ventilation systems in households and industries
10. Transport teknik 1970-1984 » Skandinavisk Transportteknik 1984-1986 » Transport Teknik Scandinavia 1986-1989 » Teknik i Transport 1989-1992 » Transport Idag 1992-2007	Specialized	Transport innovations in land, air and shipping transportation, transport and automotive equipment, automotive innovations, packaging innovations

11. Bergsmannen 1970-1977 » Jernkontorets annaler med Bergsmannen 1978-1981 » JkA: Jernkontorets annaler 1981-1987 » Bergsmannen med Jernkontorets annaler 1987-2007	Specialized	New metals, equipment and machines for mining, equipment and machines for the production of metals.
12. Telekom Idag 1994-2007	Specialized	Information- and communication technology, software.
13. Svensk trävaru- och pappermassetidning 1970-1990 » Svensk Papperstidning 1990-2007	Specialized	Machines and processes for the production and processing of wood, paper and pulp.
14. Textil och konfektion 1970-1983 » TEFO-Nytt: Special konfektion 1983-1986 Teko-Aktuellt från TEFO 1987-1993 » Struktur 1994-2007	Specialized	Textiles, machinery and equipment for the production of textiles and clothes
15. AGI Aktuell Grafisk Information 1972-2007	Specialized	Printing machines and machinery related to publishing and printing activities

Kleinknecht et al. (2002) emphasize that the adequacy and relevance of the journals are crucial for the quality of a LBIO database. The identification of appropriate sources was thus a major concern. Sweden does not only have a long industrial tradition but also a long tradition of periodical publications picturing the technological development in different industries. Examples include both specialized and general journals. The former category includes *Jern-kontorets annaler: tidskrift för svenska bergshanteringen* (mining, iron, and steel, founded 1817), *Kemiska Notiser* (chemistry, founded 1887), *Svensk trävaru-tidning* (wood and timber, founded 1885) and, *Trävaruindustrien* (wood, founded 1915).[4] General technology periodicals includes *Verkstäderna* (founded 1905) and *Ny Teknik* (continuation of *Teknisk Tidskrift*, founded 1871). Among others, the database is based on these time-honored journals.

In order to learn what journals where appropriate trade organizations were contacted. Thanks to helpful personnel a relevant sample of journals could be mapped. One criterion for inclusion was that the journal was not engaged with any company or otherwise biased. Some of the journals had ties to trade organizations while others were independent from such organizations. Another criterion for inclusion was that there was an editorial mission to report on the technological development of the industry. This criterion disqualified some of the journals that were selected in a first

[4]The present names of the journals are (in the same order): Jernkontorets Annaler and Bergsmannen, Kemisk Tidskrift (followed by Kemivärlden), Svensk Trävaru- och Pappersmasseitdning (followed by Svensk Papperstidning), and Sågverken (followed by NTT).

round. Journals on the general technological development in Swedish industries were included to ensure a broad coverage, to capture infant industries and nascent technologies that would otherwise risk go unnoticed (e.g. nano technology). The principle that was followed was that overlap is better than blind spots. The resulting data was checked for duplicates. In cases where an innovation was noted in more than one journal the quality of the data could be improved since information oftentimes was complementary.

The majority of the journals started well before the investigated period. Three journals were not; *Automation* (journal no. 1) started in 1973, *Aktuell Grafisk Information* (journal no. 15) in 1972, and *Telekom Idag* (journal no. 12) in 1994. As regards *Automation* and *Telekom Idag* the founding of these magazines is argued to reflect the technological and industrial development. The 1970s saw an increase in both demand for- and supply of automation technologies. The same remark can be made for telecommunications in the early 1990s. An exception is *Aktuell Grafisk Information*, reporting from an industry of age although started in 1972. Hence, the printing industry is not covered for 1970-1971 in SWINNO.

The selection of journals was made with the aim to cover all major 2-digit manufacturing industries as classified by ISIC (International Standard Industrial Classification) or the Swedish counterpart SNI (Svensk - Näringsgrensindelning). Table 3.1 reports what journals covered what industries. van der Panne (2007) argues that a drawback of the LBIO-method is that small industries may not be sufficiently covered since there is a risk that a dedicated trade journal is lacking. In the case of SWINNO such concerns are raised regarding non-metallic minerals (SNI 26) which do not have a trade journal. Some innovations from the industry were found in generic journals but the coverage may all the while be disputed. Computer related activities (72) and Other business activities (SNI 74) are traditionally not considered part of the manufacturing sector but was included to assure sufficient reporting about innovations related to the microelectronic revolution.

3.3.3 Journal contents

The selected trade journals all generally contain the same structure. An editorial on the general state of the industry, or a specifically relevant issue typically opens the journal. Thereafter longer and shorter notes and articles follow with focus on the development of demand, competition, supply markets, technology, regulations, and other factors affecting firms in the industry. The trade journals typically end with a section concentrating on new product announcements. Received LBIO datasets differ in terms of what type of journal content they draw upon. The Futures Group database 8,074 innovations (Edwards & Gordon, 1987; Acs & Audretsch, 1990) is based on new product announcements whereas SFINNO and SWINNO rely on articles authored by journal editors and journalists. Hence, new product announcements were bypassed and only authored articles were considered exclusively. This stance was adopted because it is assumed to increase the chance of capturing significant innovations rather than minor improvements and new product vintages with only marginal effect on the competitive landscape.[5]

The latter assumption is the very rationale of the methodology: since the editorial mission of trade journals is to report on important developments in their respective industry they should be able to separate those from the unimportant developments. Editors are assumed to be able to make judgements about which innovations are important, either from a technological, firm, or industry perspective, or all three together. When assessing the nature of trade journal contents it is important to keep their readership in mind. Business-to-business firms (which include both firms in the industry plus their customers) and suppliers are likely to value reports about any *change* that alters the competitive landscape. As goes for any firm or industry, a trade journal had better meet demand to stay relevant. This approach does not rule out the possibility that incremental innovations can be significant. Still, the chance of being featured in a journal article is assumed to increase with the level of radicalness and thus the majority of minor improvements and adjustments are believed to be filtered out by the methodology itself (van der Panne, 2007). Further, omitting new product announcements decrease the risk that only firms with forceful PR-departments will see their innovations end up in trade journals (and subsequently in LBIO-databases).

3.3.4 SWINNO innovations

While the editorial selection processes described above filtered significant innovations the constructors of the database were not exempted from the necessity to make a selection themselves. Far from every new product that

[5] In addition, van der Panne (2007) observed that counting new product announcements grossly overestimated domestic innovations because sales agencies reported diligently about foreign innovations.

trade journals reported about ended up in the SWINNO database. Several selection principles were applied to the collection of data. The following subsections will discuss the choices made to ensure a purposive sampling of innovations.

3.3.4.1 Included innovations

Three selection principles were applied in order to capture significant innovations exclusively. The first principle was to distinguish innovations from inventions. The principle follows Schumpeter's remark that inventions in themselves do not imply an economically relevant effect while an innovation is always destined for the commercial sphere (Schumpeter, 1939, pp. 84-85). In practice for an innovation to be included, it had to be possible to trace its commercializing agent, a firm. The second principle separates products from process innovations. A product innovation is defined as an innovation that is being traded on a market while a process innovation is defined as being withheld from markets and applied in-house only. The trading of production process technology is thus defined as the trading of product innovation; a market transaction is the dividing line. This principle was given by the low probability that trade journals would cover process innovations in a satisfactory way. Production processes may be a key to a firm's competitive advantage and there may thus be little incentive to submit information about them unless they are going to be sold. Undesirably, this criterion limits the possibility to pick up innovation in industries were process innovations are more important than product innovations (Pavitt, 1984). However, some process innovations have been included, amounting to a few per cent of the total. SWINNO is thus not exclusively limited to product innovations and besides a few process innovations, a few service innovations are included. A growing body of literature report the increasing importance of offering services as complements to products (Henkel et al., 2004; Berggren et al., 2005; Howells, 2004; Fölster & Grahn, 2005; Neu & Brown, 2005; Kowalkowski, 2006; Penttinen & Palmer, 2007; Gebauer et al., 2010). When reported, service innovations were included in the database. Regrettably, their nature of being intangible, with low levels of uniformity and high levels of customization, as well as their role as complements to products make them all too often bypass the radars of trade journals. For this reason only a few are captured in SWINNO.

The third principle relates to the assessment of novelty of innovations. It is commonplace in the innovation literature to rate innovations according to their impact or characteristics. Innovations may be different in both re-

Table 3.2: Practical inclusion criteria for SWINNO.

Innovation	Following the Schumpeterian definition of innovation mere inventions were excluded and only innovations already out on the market or in the process of being commercialized were included.
Innovating firm	The origin of the innovation had to be identified. No "orphan" innovations were thus included. Nor were innovations from research institutes without a commercial interface included. In cases where no innovation firm, but only a sales agency or company could be identified the innovation was still included but assigned to the commercial agent.
Product innovation	The scope was limited to product innovations. A product innovation was defined as any good, process, or service that had been or was going to be transacted on a market.
Novelty	Explicitly stated dimension of novelty.

spects with regards to the technological aspect (Henderson & Clark, 1990), the firm aspect (March, 1991; Greve, 2007), and the market aspect (Bower & Christensen, 1995; Tushman & Anderson, 1986). The innovations in SWINNO were collected because they signal an important alteration in some of the above respects. It may be a groundbreaking new technology, an entrant firm with an overthrowing innovation or an existing firm diversifying into the industry by applying technology in a novel way.

SWINNO included innovations for which there was an explicit statement in the journal about novelty. A number of variables were constructed to assure that different dimensions of novelty were being captured (see section 3.4.3). An inclusive definition of the innovations in SWINNO is thus *an entirely new or significantly improved good, process, or service that is, or is going to be transacted on a market*. The same definition is used to operationalize innovation in the Finnish SFINNO database.

3.3.4.2 Swedish innovations

The ambition of constructing SWINNO was to assemble a dataset that could be used for extensive analysis of long-term industrial transformation in Sweden. Firm strategies and the development of industries are influenced by both domestic and foreign factors (see Porter, 1990). As a small open economy Sweden is sensitive to foreign influence. Foreign innovation may alter the competitive landscape for Swedish firms. Yet, the scope of SWINNO is limited to the innovation output produced by Swedish firms. The scope is restricted because the editorial mission of the trade journals is more or less confined to the Swedish market. A number of the journals have sections with longer and shorter notes about foreign markets but it has to be assumed that this treatment is not comparable with that of the Swedish market. Hence, foreign innovation is not included in SWINNO.

The quest to identify Swedish innovations required a definition of what is a Swedish innovation. A Swedish innovation is defined as developed by at least one firm with its headquarters or a major development facility in Sweden. Another criterion is that the main part of the development of the innovation had taken place in Sweden. If it could be suspected that the firm given in the article had not developed the innovation, the firm's principal activities were checked in the Swedish firm register and a search was undertaken on the Internet. The procedure allowed for an identification of sales agencies that could be disqualified as innovators. The innovations in SWINNO are commercialized in Sweden, or in foreign markets, or both.

3.3.5 Other methodological concerns

Issues with the LBIO methodology pertain mainly to the coverage of the database and potential bias introduced by trade journal practices as regards patterns of innovation over time, across industries and firms (van der Panne, 2007). For this reason, the validity, reliability and robustness of the SWINNO database has been assessed in several ways. This section briefly summarizes the main results. For more detailed descriptions and discussions, the reader is referred to Appendix A in the current study, Sjöö et al. (2014) and Sjöö (2014, pp. 145-154).

The SWINNO database is based on major and significant innovations. To obtain an indication of the validity of the database, the data has been cross-checked with other listings of significant innovations. Comparisons with Wallmark & McQueen's (1988) publication and Sedig & Olson (2002) informed us of a large overlap (74% and 86% respectively). In order to assess the reliability of the data, comparisons have been made with CIS data for the periods 1998-2000, 2002-2004 and 2004-2006, as regards employment classes of firms and the distribution of product innovations across sectors. This comparison shows strong correlations in terms of these variables. SWINNO may however have captured relatively less firms innovating in the food and beverages industry (SNI 15), and relatively more firms in the hardware electronics industries (SNI 30-33).

There is a risk that changes and bias in publication policies of trade journals may affect the data collected. For this reason we made two assessments of the robustness of the data. Semi-structured interviews were conducted with the trade journal editors (for a detailed description see Sjöö et al., 2014 or Sjöö, 2014, pp. 150-153). The picture conveyed was that a wide array of sources spanning e.g. personal networks, industry experts, industry fairs and conferences. None of the editors stated that their main source was press releases. Moreover, the editors reported an ambition to cover innovations from all types of firms. Some editors reported that despite this ambition, in actual fact, they have tended to report innovations from large firms. However, these editors implied that this reflected the industry structure of the respective journal. As regards the change of publication policies over time, no editor reported changes related to the editorial mission of the journal or efforts devoted to report about innovations. The editors conveyed that Internet has become a more important source of information. This is likely to have enabled more brief notices on product innovations. However, since there is limited space and author resources, we conclude that it is unlikely that edited trade journal *articles* have increased to any greater extent by the Internet. The interviewed editors did not report major changes in publication policies or selection principles.

Though publication policies have been indicated to be consistent, there still is a possibility that the data reported is heavily influenced by one or more trade journals. This possibility motivated a quantitative assessment of robustness. The question posed is whether the patterns of innovations over time, is sensitive to the inclusion or exclusion of certain trade journals. By comparing the distributions of innovations for different choices of journals one may examine whether the results are similar or not, i.e. robust to our choices of journals or not. The distribution of innovations per sector and the size distribution of innovating firms have been found to be largely insensitive to the choice of journals. As regards the distribution of innovations over time, the results show that the pattern observed was not sensitive to the choice of trade journals. At the industry-level, machinery (SNI 29), computers (SNI 30), telecommunications (SNI 32), software (SNI 72), fabricated metal products (SNI 28) and rubber and plastic innovations (SNI 25) were found to be robust. Innovations in these product groups make out a substantial share of all innovations and have contributed greatly to the to the variations over time. Thus, one may conclude that the aggregate pattern of innovation is a robust result of the database. Other patterns of innovation over time may have been dependent on a few specialized trade journals (for instance wood products).

3.4 The SWINNO database: Variables and Results

The SWINNO database contains a range of variables that enable a thorough and at the same time comprehensive analysis of innovations, innovation processes and innovating firms. The following subsections will describe variables related to all of the above and in addition present central results from the SWINNO database. The SWINNO database contains variables pertaining to a) the innovation process, b) the innovation, and c) the innovating firm(s).

The structure of the SWINNO database is based on the information about the innovations given in the trade journals. A large amount of textual information has been codified and classified into categorical and ordinal variables. The most fundamental data recorded is: the description of the innovation, the name of the innovation and the name of the innovating firm. An example of the basic information of the database is given below.

3.4.1 What and when: mapping types of innovation and patterns of innovation activity over time

The database contains 4852 observations of innovation activity. The innovations known to have been commercialized during 1970-2007, make up 4030 of these observations. Another 5 innovations were known to have been commercialized after 2007. For another 462 observations, the innovations were stated to be commercialized at some point after the latest article mentioning the innovation. Other observations (222) were reported to be in a state of early development (constructing prototypes, or, as many

Table 3.3: Count of innovation by type.

Type	Count
Commercialized (1)	4035
To be commercialized (2)	462
Process innovation (3)	109
Under development (4)	222
Commercialized before 1970 (5)	24
TOTAL	4852

pharmaceuticals, being tested for a long period of gestation). Information on the process innovations of firms were also gathered, though these constitute only a very small portion of the database (109). 24 innovations in the database were commercialized before 1970. This thesis is based on the 4140 innovations which are commercialized in 1970-2007 or process innovations.

Information about the innovation process has also been gathered when information was given in the articles. For all of the commercialized innovations, a commercialization year has been recorded based upon the information given in the articles. For the large majority of these cases the year of commercialization was explicitly mentioned. In some cases when the year of commercialization was not immediately retrievable, the year of the first article when the innovation has been stated as commercialized has been used as a proxy.

3.4.2 The industrial nomenclature employed in this work

In this thesis, patterns of innovation are studied across industries. The notion of "industries" is in the current work based on the industrial classification of innovations, rather than classifications of the main activities of innovating firms. In the construction of the SWINNO database, all innovations were classified according to their product group and given a five-digit code according to the Swedish standard industrial nomenclature SNI 2002 (Svensk Näringsgrensindelning 2002). This means that the innovations are coded in a coherent way throughout the period, enabling a detailed study of patterns of innovation on several levels of analysis. However, though the most detailed classification may be advantageous in general, it is not at all occasions the preferred level of analysis.

A nomenclature has been developed to attain both a high level of detail and meaningful differentiation between product groups. In most five digit product categories the number of innovations are very low, which makes inference of broader patterns difficult. Therefore the analysis in general departs from a three digit classification.

However, some three digit sectors, most notably the machinery sector, contain considerably heterogeneous products. To enable consistent analysis throughout this work that allows for both statistical inference and a high level of detail, a nomenclature has been constructed for the purposes of this thesis. The rule of thumb has been to retain the lowest level of detail possible. Industries have been aggregated only when 1) the average count of innovations are lower than one innovation per year and 2) the sector can be aggregated together with other similar sectors. The resulting nomenclature is referred to as 'industries' and is used throughout this work (with minor revisions in Chapter 5). The industrial nomenclature is found in its entirety in Appendix B.

While this nomenclature is used throughout the thesis, it has been convenient on occasion to summarize information on the two-digit level of industrial classification. When SNI codes appear in a context in which two-digit level industries are discussed only two digits are used (e.g. SNI 15 or SNI 29). When SNI codes appear in a context in which the industrial nomenclature of this thesis is employed, SNI codes will have three to five digits (e.g. SNI 150 or SNI 29220).

3.4.3 Novelty

The novelty of innovations is a fundamental dimension, stressed not the least by the large literature distinguish basic, or radical, innovations from incremental ones, or macro-inventions from micro-inventions. The current study makes no attempt to distinguish innovations that have been "basic" or "radical" in the sense implied in the long wave debate (see section 2.3.1). In the SWINNO database the journal articles however give the opportunity to classify innovations according to their degree of firm and market novelty. In previous LBIO-studies, and CIS studies the degree of novelty has been assessed through firm novelty and market novelty. The firm novelty variable regards the degree of novelty of the innovation from the firm perspective. Firm novelty informs us about nascence conditions: did the inno-

Table 3.4: Criteria for the classification of firm novelty.

	Criteria
Entirely New	Innovation is described as a breakthrough or significant improvement and requires a reconfiguration of the firm's knowledge base or field of technology
Major improvement	Innovation is similar to previously introduced products / innovations of the firm but entail significant improvements or exploit new technologies.
Incremental	New generation, only slight improvements made on a previous innovation

vation spring from some previously developed technology or function or is it totally new from the firm's perspective? Several studies provide similar taxonomies of the firm novelty of innovation. One which relates novelty to the complexity of innovation identifies innovations as competence enhancing or competence destroying (Henderson & Clark, 1990). The taxonomy provided here overlaps more closely with a distinction between explorative and exploitative innovation (March, 1991, see also chapter 2). An innovation was classified as "entirely new" if the firm ventured into a new field of technology and the innovation required a significant reconfiguration of the firm's knowledge base, and/or if the innovation was described as being a breakthrough or significant improvement in a technological or functional sense. An innovation was considered 'a major improvement' if the innovation overlaps with previous products but was described in the article to entail a significant improvement and/or the technology has changed greatly. An incremental improvement is defined as innovations when only slight changes have been made to a previously existing innovation. A summary of these categorizations is given in Table 3.4.

The other type of novelty considered in the database is market novelty where one may distinguish between the innovation being "new to the world market" or "new to the Swedish market". Due to the difficulties inherent in classifying market novelty we classified only those innovations explicitly mentioned as new to the world or Swedish market.

3.4.4 User industries

The articles enable a consistent and detailed account of the intended and actual use of innovations in different sectors. This information may be employed to study the flow of innovations across industries (see chapter 6). Mappings of the patterns of production and use of inventions or innovations have been used since the 1980s, using patent data (Scherer, 1982; Verspagen, 1997; van Meijl, 1997; Nomaler & Verspagen, 2008, 2012) and innovation output data (DeBresson & Townsend, 1978; Robson et al., 1988; DeBresson et al., 1996), for various purposes. A key difference with respect to the SAPPHO database (Robson et al., 1988) is that survey material was largely used to map this variable. A difference with respect to Sfinno is that 'user sector' was defined as a sector in which the innovation has been used (Saarinen, 2005). Since the SWINNO data insofar is not complemented with survey data, the information on the sector of use rather is taken to be a measure of to what sector or sectors of the economy the innovation has been or is being marketed. The limitations of this variable lie also in the difficulties in discriminating when an innovation began to be used in a certain sector. Thus, the variable does not strictly speaking convey a story of diffusion.

The User sectors are classified according to SNI 2002 at the lowest industry-level possible. Apart from the given SNI codes two auxiliary categories have been used: final consumers (101) and general industry (100). An innovation is allowed to have up to eight different user sectors. A general purpose innovation could thus either have been classified as 100, or be given a sizeable number of user sectors. In principle, filling in several user sectors when explicitly mentioned has been preferred to classifying the innovation as an innovation of general use, unless it is clear that the innovation may be used in any industry.

The fundamental results concerning the patterns of use of innovations are presented in chapter 6.

3.4.5 Data on the innovating firm

Though centered on innovation output, the SWINNO database also registers information on the subjects of the innovation process, i.e. the innovating firms. The innovating firm is in SWINNO considered the firm that has developed the innovation. When several firms have been involved in the

Table 3.5: Summary of information of the innovating firm(s).

	Description	Observation years covered	No. Observations
Employment class	16 employment classes	1970-2007	4375
Branch of economic activity	5 digit level SNI69 for 1970-1991, SNI92 for 1992-2001 and SNI2002 for 2002-2007)	1970-2007	4219
Start Year	Year of registration of the firm, if registered 1973-2007	1973-2007	2383
Turnover class	12 turnover classes	1993-2007	1558
Geographical location	Municipality	1970-2007	4460

development process, the firm which has had main responsibility has been singled out and the others recorded as collaborating firms (see variable 'collaboration'). When a firm abandons the development of an innovation to another firm, both firms are recorded in the database, but only the latter is defined as the innovating firm. The former firm is then recorded as a prior developer of the innovation (variable "Other_ Dev").

According to the above definitions, the firm developing the innovation has been identified for all except 146 innovations. These are cases when the only firm involved had not taken part in the development of the innovation. Such innovations may for instance have been developed entirely in universities or by a single inventor, assigning the marketing to a previously uninvolved firm.

Auxiliary data for the firms has been retrieved from Statistics Sweden at the year of commercialization of the innovation (or first mentioning in an article) for a total of 4469 innovations. By linking the firm name to an organization number, information has been assembled by plants. In total these encompass 2651 different plants with a unique organization number. The economic information gathered is summarized in the Table 3.5.

3.5 Data used in this thesis

Apart from the basic information on commercialization years, industries, user industries, firm size and firm novelty, this study examines the origins of innovation through a quantitative and qualitative approach.

3.5.1 Problem-solving innovations

In chapter 2, the main classification of innovations into problem-solving innovations and innovations responding to technological opportunities was introduced. This classification is at the center of this study. The main results are presented in the next chapter (Table 4.5), but the underlying methodology of the classification is presented here. The classification into problem-solving innovations has departed from information available in the trade journal articles. The classification was based upon direct textual evidence of descriptions of the innovation. An operational definition of a problem may in some cases lie close to the notion of obstacle, i.e. a factor which impedes the attainment of some firm-specific, industrial or societal goal. In other cases the description of the innovation process allowed for the distinction of a factor, which the firm managers *perceived* as a problem that needed to be solved. An innovation was considered problem-solving if the development of the innovation was explicitly described as aiming to overcome an obstacle or problem as defined previously. For the problem-solving innovations a note was taken of this textual evidence, which has served as the basis of qualitative descriptions of innovation activity found in the chapters 4-7.

An example of the underlying evidence of a problem-solving innovation can be given here. The example concerns Masonite AB, a producer of wood products, that responded to the raw material shortage in the forestry industry in the beginning of the 1970s:

> "The raw material shortage and energy crisis made many forest industry men wonder what the future had in store. The shortage of timber will probably lead to a radical change in the use of wood based materials for building purposes. When standing timber prices rise, new technical-economic solutions of the problems are developed by the application of new constructions and new materials. It is most likely that to a higher degree than is the case today the constructions will include several combinations of material in which optimum advantage will be taken of the properties of the respective materi-

als. The difficulties resulting from the energy crisis induced Masonite AB to set up new production and marketing aims and to conduct a new policy accordingly. In 1973, with financial support from the Norrland development Fund, the company started intensive research and development work. Enthusiasm jointly with know-how brought about the new building system which promises revolutionary innovations" (*Svensk Trävaru- och Pappersmassetidning* 1976:7, pp. 539, 541, 544).

In this example there is a clearly defined, albeit perceived, problem. On the basis of such evidence, the innovations were then classified into four types of problem-solving innovations (see Table 2.5). This innovation has been classified as an "induced innovation", responding to an economic problem, the timber shortage.

3.5.2 Technological opportunities

The notion of technological opportunities can be understood broadly or narrowly. A narrow definition is to include only those innovations for which opportunities drove the development of the innovation. In chapters 5 - 7, only those innovations that *explicitly* cite opportunities as spurring the development of the innovation are considered to have responded to opportunities. The distinction of innovations that exploit technological opportunities is based on explicit mentioning in the journal articles of a technology, which contributed to or enabled the development of the innovation. In these chapters opportunities are divided as stemming from a) new technologies and materials and b) scientific discoveries or academic research.

However, to study the macro-patterns of the technology shifts that took place during the period, a broader definition is useful. The broader definition of opportunities includes all those innovations that exploit new technologies in their core functions. The main technology shift that took place during the period was the microelectronics revolution. The broadest definition of opportunities used in this thesis includes not only innovations that explicitly have cited an opportunity, but also innovations that make use of microelectronics or computer technology in their core functions. To achieve this broader classification innovations that exploit the To study the broader technology shifts that took place during the period this definition is used in chapter 4. In this chapter, technological opportunities are grouped into three classes of technologies: 1) Micro-electronics, 2) biotechnologies and 3) other technological opportunities. The results of these classifications are presented in chapter 4 (Table 4.5).

The factual difference between the broad and narrow definitions is 305 ICT innovations (SNI 30-33 and SNI 72, being computers, software, telecommunication equipment, measuring equipment and electric appliances) most of which were launched during the period 1990-2007. These 305 were included in the broader definition used in chapter 4. In the remainder of the thesis they have been excluded from the definition of technological opportunities.

3.5.3 Journal articles as sources of qualitative information

Apart from being the source of the variables of the SWINNO database, the journal articles are throughout this work used as sources of information on the process of innovation and the innovating firm. The textual information is used to provide nuances, contrasts and examples and to describe the historical development of industries and firms. As described previously, a criterion for selection of journals was their independence. Articles were included provided that they were independently edited. However, the information contained in the articles was often based upon interviews, press releases and sometimes the journalist's own research.

The description of innovations based on the journal article cannot possibly be complete. To select relevant examples the description of innovations have in all chapters departed from the following generic routine. As previously stated all innovations were classified according to the information contained in the journal articles into categories of problems and opportunities. After this classification, the material was gone through by industries. The guiding question in selecting examples was: Are there other innovations responding to the same type of problem or opportunity? If there were examples of innovations citing similar problems or opportunities, they were considered to reflect a more generic problem or opportunity. In cases when such innovations have been numerous or deemed of importance to the aim of the analysis they have been included. In chapter 6, the routine required a first rough classification of innovations into whether or not they can be considered to reflect a technological imbalance. In the subsequent steps the material was gone through with the guiding question whether there were other examples of similar problems. The analysis eventually arrived at a set of interrelated problems (problem complexes, as it were) centered on the same fundamental problem.

In the empirical analysis in chapters 4-7, numerous examples are given and quotations are sometimes rendered from the trade journal articles. In general these articles are written in Swedish. Quotations have therefore been translated to Swedish by the author of this thesis. With several thousand trade journal articles, it has been convenient in the SWINNO database to reference articles by journal name, year, number and page (e.g. "*Ny Teknik* 1970:1, p. 1") instead of specifying the article title and article author(s). The same applies throughout this study.

3.6 Auxiliary data used

Apart from the data assembled within the SWINNO database three sets of data are used in this thesis. For use in chapter 5 series for value added and value added price deflators were retrieved and a time series was constructed 1969-2007 based on series from SCB Industri (Del 1) 1969-1990 and Statistics Sweden (www.scb.se) 1990-2007.[6] Due to breaks in the industrial classification system the series were linked together in a way as consistent as possible. The change of nomenclature between SNI 69 and SNI 92 has been a challenge for most economic historians working with longer economic time series. To date there has been one study employing consistent value added volume series at the three digit level or lower for this period of time (Svensson Henning, 2009). In other works (e.g. Schön & Krantz (2013)) a longer time perspective has motivated aggregation of industries into broader sectors for consistency. The value added series employed in this work do not measure up to the quality attained in Svensson Henning (2009), as the series constructed there employed linking procedures of the firms' industry-codes. Therefore, for an authoritative classification of industries into advancing, stagnating and receding the reader is referred there. The calculation of value added volumes for the entire period 1970-2007 posed several difficulties. Some crude assumptions were necessary to link the value added series in current prices. PPI series 1970-1995 for SNI69 and

[6]For the latter period the sources were "Industristatistik efter näringsgren SNI92 avdelningsnivå. År 1990-1996", "Basfakta företag efter näringsgren SNI92, tabellinnehåll och tid. År 1997-2002" and "Basfakta företag enligt Företagens ekonomi efter näringsgren SNI 2002, tabellinnehåll och tid 2003-2008". Producer Price Index series were obtained from "Producentprisindex (PPI) efter varugrupp SNI69. År 1969-1995" and "Producentprisindex (PPI) efter produktgrupp SPIN 2002. År 1990-2009". All available from www.scb.se (130701).

Table 3.6: Data and central variables used in this thesis.

	Quantitative data	Qualitative data	Auxiliary data
Chapter 4	Number of innovations per year of commercialization, and by industry	Problem-solving innovations and other descriptions of innovations	National accounts 1970-2007
Chapter 5	Employment classes of firms, origins of innovation in problem-solving and technological opportunities, Firm and market novelty	Opportunities, problem-solving	Volume series, by industries 1969-2007
Chapter 6	Supply and use of innovations	Opportunities, problem-solving	
Chapter 7	Start year of firms, Problem-solving and technological opportunities	Cases of ICT innovations	Financial accounts, 44 firms and 3 corporate groups

PPI series 1990-2007 were linked together following as closely as possible the linking schedule in MIS 1992.

For chapter 7, the financial accounts for 150 firms active in the hardware ICT industry was retrieved in order to provide measurements of firm-level negative performance feedback and excess resources. The financial accounts were retrieved from the Swedish Company Registration Office (Bolagsverket). Of these 47 firms were selected for a closer study, out of which three were large corporate groups ASEA/ABB, Ericsson and AGA. The underlying choices and issues are described more carefully in chapter 7.

3.6.1 Summary of the data used in this thesis

To give the reader an overview, a summary of the data used in this thesis is given in Table 3.6. The table summarizes the data used by chapter and level of analysis.

4. Innovation in periods of crisis and growth

4.1 Introduction

Do firms innovate primarily when markets promise profits, high demand and buoyant opportunities or during periods of crisis and declining profits, responding to a threat of failure? This is a long-standing question that has been much debated, and has obtained a rekindled interest in the wake of the global recession of 2008 and the recent energy crisis (see e.g. Filippetti & Archibugi, 2011; Archibugi & Filippetti, 2011; Paunov, 2012; Berchicci et al., 2014). Previous research has proposed competing hypotheses about the 'when' of innovation. One strand of research has investigated the positive or negative association between business cycles and innovation activity. Geroski & Walters (1995) found support for a positive connection between GDP growth and the commercialization of innovations. Brouwer & Kleinknecht (1999b) found evidence of a positive impact of demand growth on R&D efforts. Others have found that innovation takes place during industry downturns (Berchicci et al., 2014).

Another strand of research has discussed the evidence of longer cycles in innovation activity. Schumpeter (1939) recognized the possibility that innovations could be diffused in cycles of different length. The bulk of the literature has discussed the variation of innovations in long waves, or Kondratiev waves, of 45-60 years of duration. Taking a longer time perspective, some authors have proposed that basic innovations are likely to be spurred by the adversities of long wave downturns (Mensch, 1979; Kleinknecht, 1987). Others have proposed that innovations are more likely to be spurred by increasing demand, and positive prospects in the recovery from deep downturns (Clark et al., 1981; Freeman et al., 1982; Freeman &

Perez, 1988).

Schön (1994, 1998, 2006, 2010) has proposed a historical generalization based on patterns of growth and innovation in the Swedish economy. In this view, innovations have evolved in an interplay with the patterns of economic growth. New technologies, such as micro-electronics, have been diffused after the structural crises of the 1850s, 1890s, 1930s and 1970s. In this perspective, the underlying inventions may have been developed previously but the structural crises have broken down obstacles to the adoption, diffusion and further development of such technologies (Schön, 2006, p. 82). The technological and economic development then follows a pattern in which investment is first directed towards overcoming obstacles and enabling the exploitation of new technologies. When the technology matures a wider diffusion is made possible, reaching final consumers. This pattern, the so-called structural cycle, has formed a pattern of roughly 40 years of duration.

To what extent has innovation activity varied with periods of economic crisis and growth, during the period studied?

This study takes view that the question of whether innovation is concentrated to periods of crisis or growth must be answered while allowing for a host of positive and negative factors to be simultaneously at work at any given datum. This study thus examines the relative influence of positive and negative factors at any given datum. The SWINNO database enables precisely a simultaneous analysis of patterns of innovation in periods of crisis and growth, and the relative importance of positive or negative factors in inducing innovation as creative response.

The issues dealt with in this chapter is thus if and how innovations are related to economic crisis and growth, and how innovations have been developed in an interplay between new opportunities and pressures to transform in the Swedish manufacturing industry. This chapter examines how innovation activity developed in the Swedish manufacturing sector during the period 1970-2007 and explains patterns of innovation by way of a historical and statistical analysis of the positive and negative factors that have spurred innovation. The subject matter is approached by two sets of questions.

The first question focuses on the 'when' of innovation:

- *Did firms innovate during periods of crisis or growth?*

This question is answered in section 4.3 by an analysis of the 'when' in the overall pattern of innovation and by a decomposition of the pattern of innovation by industries.

The second set of questions focuses on the determinants of innovation, following Dahmén (1950) understood in terms of positive and negative factors:

- *What patterns of innovation can be discerned during the period and how can they be explained?*
- *To what extent and how were innovations in the Swedish manufacturing industry the creative response to opportunities or problems?*

These questions are answered in sections 4.3 and 4.4 by a qualitative and quantitative analysis of innovation as the creative response to technological opportunities, technological bottlenekcs and economic, environmental and organizational problems.

The chapter is organized as follows. First the approach to the issue at hand is discussed in section 4.2 as regards the variables used and the Swedish business cycle chronology. In section 4.3 the main empirical results of the SWINNO database are then presented as regards the patterns of innovation. The industries and positive and negative factors that account for these alterations in the count of innovation are presented. Thereafter, in section 4.4, the patterns are described and analyzed in more detail in terms of the pattern of innovation during the first half (1970-1989) and the second half of the period (1990-2007). This section aims to describe *how* innovation was responding to technological opportunities, waning demand, environmental and organizational problems. Section 4.5 concludes.

4.2 Approaching the 'when' and 'how' of innovation

4.2.1 Event counts

Previous empirical research on temporal patterns of innovation have typically relied on event counts. A fundamental issue is therefore what event to count. Patent counts have typically been analyzed by year of application or by the year it was granted. Innovation counts have been analyzed by the year of commercialization or by the year in which search or development was initiated. Most studies employing innovation output data have employed the year of commercialization to assess long run and short run patterns of innovation (e.g. Mensch, 1979; Kleinknecht, 1987; Geroski & Walters, 1995; Greve, 2003a,b). It is a strength that the SWINNO database records both the year of commercialization for all innovations that were commercialized and the year of development initiation, though the latter has been recorded to a lesser extent.[1] For all commercialized innovations, a commercialization year has been recorded based upon the information given in the articles. For the large majority of these cases the year of commercialization was explicitly mentioned. In some cases when the year of commercialization was not immediately retrievable, the year of the first article when the innovation has been stated as commercialized has been used as a proxy. For 865 innovations the year of the initiation of development of the innovation has also been recorded.

One of the more basic ways in which the long term changes in innovation activity may be assessed is by the sheer count of innovations by year of development initiation or by year of commercialization. Thus, the measurement is based on event counts. Arguments can be made for the relevance of both measures. The time of market launches of innovations is well-suited for analysis of the clustering of innovation in time, as "first some, and then most, firms follow in the wake of successful innovation" (Schumpeter, 1939, p. 100).

Thus, what matters in this process is the commercialization of innovations. On the other hand, the year of commercialization does not necessarily reveal when the actual creative response takes place. Response can consist in 1) the initiation of (problemistic) search or 2) the acceleration or re-orientation of extant development projects. Greve (2003b, p. 103) uses innovation launches to test the theory of negative performance feedback (see chapter 7) but cautions that "innovation launches are not the cleanest possible test of the theory, however, because they are a complex behavior where long-term firm capabilities and investments in research affect the outcome". To the extent however that response to adversity or opportunities consists in the second type of response, the year of development initiation may fall short.

At this juncture the count of innovations by the *year of commercialization* is employed to picture the development of innovation activity throughout the period 1970-2007. The year of commercialization is also used to picture the varying concentration of innovation to periods of crisis and growth.

[1] The year of commercialization tries to report the year at which the innovation was launched on the Swedish market.

This means that the patterns of innovation over time reflect launches of innovations, but more roughly the timing of creative response.

4.2.2 Innovation and economic cycles

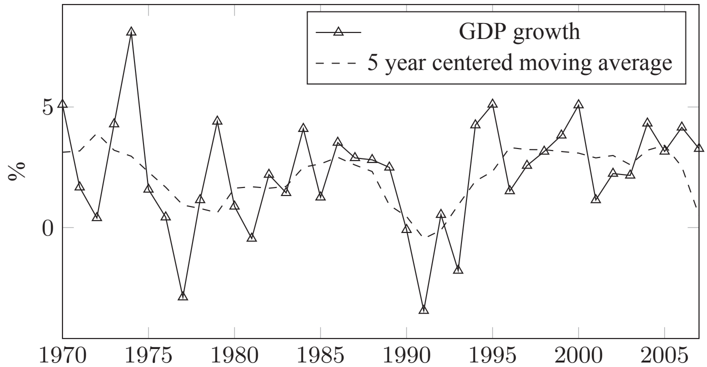
A second issue concerns the approach to the comparison of patterns of innovation, with business cycles or other cycles. Following Schumpeter's 1939 notion that innovation activity in principle may follow economic cycles of lengths between the Kitchin cycle of 3-4 years and long waves of 45-60 years of duration it would be desirable to compare the patterns of innovation with both shorter and longer cycles. This is the approach used by some scholars (Silverberg & Verspagen, 2003; de Groot & Franses, 2009). The short time period of the study however does not favor a quantitative analysis of counter-cyclical or pro-cyclical patterns of innovation. The aim is therefore not to examine the correlations between economic indicators and innovation activity. Instead, the approach taken is to compare patterns of innovation with the Swedish chronology of business cycles in terms of a statistical and qualitative description of the 'when' of innovation activity across industries (section 4.3.1) and a statistical and qualitative description of patterns of creative response over time (section 4.3.2). The industrial patterns are analysed in terms of their long-term trends. These decompositions may be said to explain the macro-pattern of innovation activity.

4.2.3 Business cycles and the Swedish chronology of economic crises and growth

Previous research on economic crises in Sweden has dated two major crises and two recessions during the period of study. In the two Figures 4.1 and 4.2 the growth of GDP and total investment in constant prices are shown. The Figures show four periods of successive years when GDP growth has been less than 2% or when investment growth has been negative. In chronological order:

- the crisis of the 1970s, 1975-1978,
- the recession of 1980-1981,
- the crisis of the 1990s, 1990-1993, and

Figure 4.1: GDP growth fixed prices, 1970-2007.



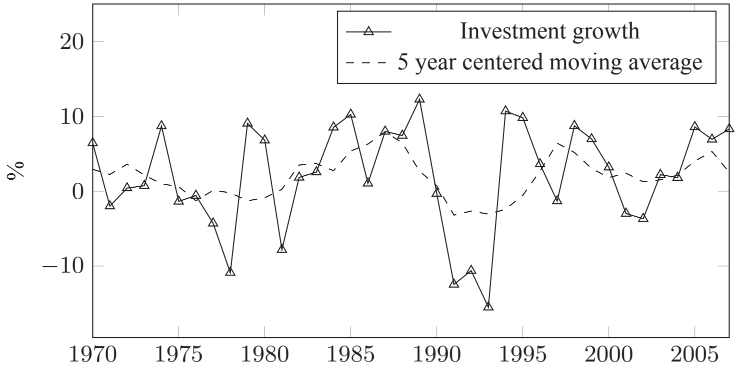
Source: Schön & Krantz (2013)

- the recession of 2000-2002.[2]

The crisis of the 1970s was triggered by the first OPEC crisis in 1973, resulting in shock increases of oil prices and a stagflation situation unfolding in several Western countries. A temporary economic expansion took the edge off the oil crisis, but in 1975 a deeper depression unfolded especially in the mining, steel, shipbuilding and parts of the forestry industry. In these industries, the shipbuilding and steel industries in particular, an over-capacity had built up due to the initiation of optimistic investment projects, that turned out to be malinvestments (Dahmén & Carlsson, 1992). In the characterization of Schön (1994, 2006, 2010) the crisis of the late 1970s was a *structural crisis*. Schön (1994, 2010) has stressed that structural crises imply an ending of periods of structural stability, and have been followed by periods of reorientation of growth and technological development. Thus these crises are those that have formed the boundaries of periods of structural stability. In the view of Schön (1994, 2010) these crises have often been the most far-reaching in the sense of affecting large parts of society, not only industry. There seems to be a consensus that the crisis of the 1970s was crucially structural in character, shaped by malinvestment, maladjustment and overcapacity or overproduction in key industries such as the metal industries (steel and iron), the textile industry and shipbuilding industry. For instance, Örtengren & Carlsson (1979) found that the crisis of

[2]Investment growth was negative in 2001 and 2002 but the recession began in late 2000.

Figure 4.2: Investment growth, constant prices, 1970-2007.



Source: Schön & Krantz (2013)

the 1970s was more characterized by structural problems, than any of those before.

The second major crisis took place in the 1990s. Edvinsson (2005, 2010b) found the crisis to be the most severe in Swedish history in terms of GDP growth. In most descriptions of this crisis, the proximate causes are considered to lie in errant policy making. Both domestic and international factors played a role. Jonung (1994) points at the driving forces of the crisis as "primarily domestic" (Jonung, 1994, p. 243) and stemming from the devaluations (1981-82) and the deregulation of capital markets in 1985, bringing about a classical boom and bust. The overheating was further aggravated by the currency deregulation in 1989 (the so-called "November revolution") that lead capital abroad, and to the ensuing real interest rate shock. The Swedish Central Bank was forced to defend the currency exchange rate by keeping a higher real rate of interest. All of this led of course to a plummeting in investment, with serious social consequences in the increased unemployment from 1-2% to 10% (Jonung, 1994, pp. 245-247). In addition to this, the situation was further aggravated by the Swedish Central bank's decision to peg the Swedish krona to the ecu (European Currency Unit) in 1991. As a crisis of the European Monetary system (EMS) unfolded, the Swedish krona suffered speculative attacks, together with the British pound and the Italian lira (Ljungberg, 2004; Schön, 2010).

In the view of Schön (1994, 2010) the crisis of the 1990s can be characterized as a "transformation crisis". Such crises have followed upon periods of renewed technological development and may lead to a subsequent strengthening of the orientation in new technologies Schön (1994, pp. 64-66). However, Krantz (1993) took issue with what kind of crisis took place during 1991-1994. Arguing that institutional and economic rigidities and inertia had effectively hampered the necessary adjustment to new conditions of competition and technologies, Krantz purported that the Swedish economy since the 1970s was in a state of unreleased structural crisis. As it were, the expansionary fiscal policy, and the series of devaluations during the 1970s and 1980s, certainly served to appease the social effects of the crisis, but they did not bring about the dismantlement of inefficient firms and malinvestment.

The recovery of the Swedish economy after the crisis of the 1990s was spearheaded by the telecommunications and biotechnology industries. The international explosive development in Telecommunications and IT was fuelled by technological opportunities and optimism. In Schön's perspective this was a period of expansive transformation until the onset of a "culmination crisis". Several factors worked together to bring about a stock market crash and an international recession in 2000-2002 in which Swedish industries were taking part. Ericsson and many smaller IT and telecom companies were hit hard by the crisis. The over-optimism surrounding the new technologies had led a classical speculative boom and bust (Freeman, 2001). This recession does not show up in negative GDP growth, but depressed the rate of investment growth (Figure 4.2).

Some issues pertain to the dating of the crises, that has differed somewhat in previous research. Edvinsson (2010b) dates the two major recessions to 1976-1978 and 1990-1994 defining major recessions as years when the level of GDP is lower than two years before. A "mini recession" was dated to 1979-1981. Schön (1994, 2010) dated the structural crisis to the period 1975-1980. Dahmén stated that the the structural problems had been solved in the beginning of the 1980s, at least since the currency devaluation of 1981 (Dahmén & Carlsson, 1992, p. 62). Erik Lundberg considered the whole period 1974-1982 as a single period of crisis (Lundberg, 1994, pp. 140-172). Moreover, Schön also dated the transformation crisis to 1991-1994.

Table 4.1 presents the chronology used in this study. The chronology corresponds roughly to the observed periods of crisis and recessions, observed in Figures 4.1 and 4.2. For statistical comparability I have chosen to use five year periods, except the last eight years of the period that are divided into a recession period 2000-2002 and the boom 2003-2007. Though

Table 4.1: Business cycle chronology.

Period	Business cycle	Structural cycle	GDP growth (%)	Investment growth (%)
1970-1974	Expansion	*Rationalization*	3.32	1.7
1975-1979	Crisis	Structural crisis	0.41	-2.81
1980-1984	Recession (1980-1981)	*Transformation*	1.81	1.47
1985-1989	Expansion		2.91	7.56
1990-1994	Crisis	Transformation crisis	-0.25	-7.86
1995-1999	Expansion	*Culmination of transformation*	2.78	4.44
2000-2002	Recession	Culmination crisis	1.69	-3.27
2003-2007	Expansion	Rationalization	2.37	7.32

the structural crisis could be treated as a coherent period of crisis, as did Lundberg (1994), it is considered useful for analytical purposes to divide the crisis in two stages. Despite the recession, there were signs during the years 1980-1982 of a recovery underway. However it must be noted that the structural crisis could well be extended on other premises. If one considers the oil crisis, and the slowdown in for instance shipbuilding and basic metals it is possible to argue for a slightly longer period of structural crisis. In some industries a crisis situation was clear already during the international oil crisis in 1973-1974, despite the domestic boom.

4.3 Basic results: structural change and structural boundaries in the Swedish pattern of innovation activity

A main result of the SWINNO database is that there were two larger increases in the overall counts of innovations localized to the end of the 1970s and the beginning of the 1980s, and the end of the 1990s (see Figure 1.1). The first of these increases coincides with the structural crisis. The second of these coincides with a boom period characterized by a wider diffusion of ICT-technologies.

During the period, drastic technological shifts took place. In the midst of the structural crisis of the 1970s, vast opportunities emerged through the third industrial revolution, centered on microelectronics. The diffusion of microelectronics technology during the late 1970s and the 1980s paved the way for e.g. CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) but also contributed to the development of biotechnology during the 1980s. Meanwhile, large parts of the traditional industry, steelworks and shipbuilding industries in particular, were under pressure to transform. After the crisis of the 1990s, electronics was diffused on a broader scale through the installation of Internet, entailing a radically different environment for technological change. The latter half of the period can thus be described as a period in which microelectronics entered into the households, through e.g. personal computers, mobile telephones and through the diffusion of Internet. A basic finding of the SWINNO-database is that this description is reflected in the development of innovations across industries.

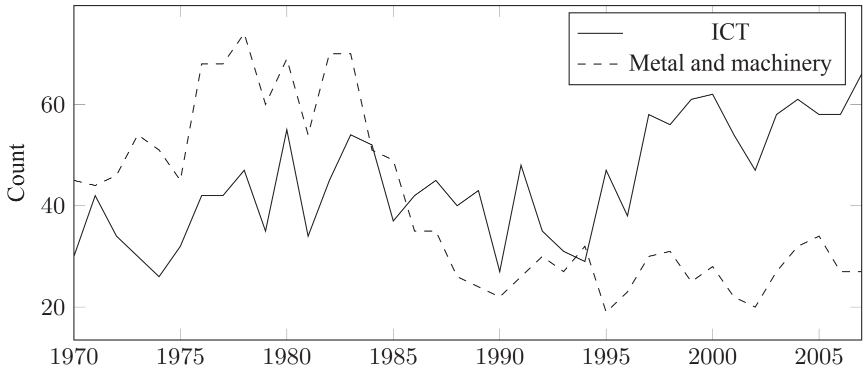
4.3.1 Industrial patterns of innovation

In total 4140 innovations were commercialized during the period. The most important products were Machinery (1195), electronic equipment (600) and telecommunication innovations (288). However, these industries followed quite different patterns over time. By comparing the count of innovation over time a picture emerges of some industries forging ahead, experiencing rapid technological change and some industries falling behind.

A telling comparison is that between the 'traditional' industries, metals, fabricated metal products and machinery sector, and on the other hand, the innovations in the growing ICT industry. In Figure 4.3 the count of Metal, Fabricated metal products and Machinery innovations are compared with the count of ICT innovations. The ICT-sector is notoriously difficult to define. At present, the notion is taken to denote innovations being typical ICT products: computers and office machinery (SNI 30), telecommunication products and services (SNI 32 and 64), electronic equipment (SNI 33) and software (SNI 72) but also electrical components and apparatus (SNI 31). I will later in this chapter employ a notion of innovations that *exploited* technological opportunities in ICT, that includes machinery innovations that made use of micro-electronics.

From the Figure 4.3 variations in the pattern of innovation can be observed. The traditional industries were strongly decreasing and the ICT industries have increased during the period. It is striking however that metal and machinery innovations were increasing during and following the structural crisis. Moreover, one may notice that an increasing number of ICT innovations were introduced during and following the structural crisis. The increase in the count of ICT innovations during the late 1970s and the 1980s particularly concerned computers, computer systems and control apparatus. An increase throughout 1990s can also be observed. During the 1990s, a majority of the ICT innovations were directly pertaining to the diffusion of Internet and telecommunication equipment and networks. These innovations were geared towards final consumers and a wider use of ICT.

Figure 4.3: Count of innovations in the ICT and Metal and machinery industries, by year of commercialization 1970-2007.



In order to further examine and describe these patterns, industries have been grouped together according to the trend in innovations over time. Each industry was grouped according to the period when the highest count per year occurred. In accordance with the business cycle chronology indicated in Table 4.1, industries were grouped according to maximum average counts during the periods 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2002 or 2003-2007.

The results may be summarized in three main patterns among the various industries. The detailed statistics are given in Tables 4.2, 4.3 and 4.4. The total count of innovations in these groups of industries are shown in Figure 4.4.

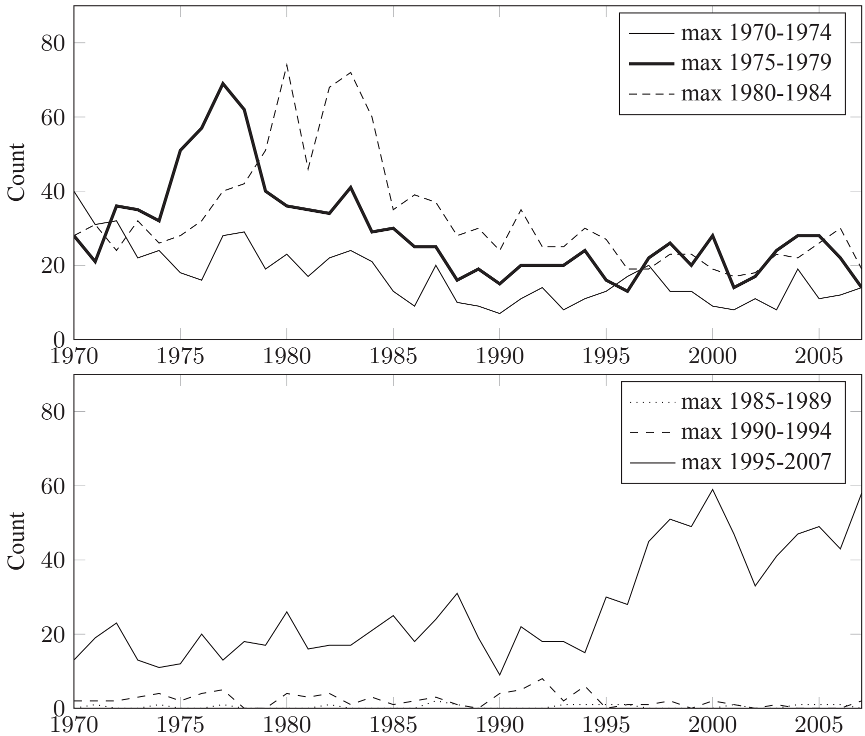
Innovations in the first group of industries had a negative trend over the period but increase sharply during and shortly after the structural crisis of the late 1970s. These were industries that may have responded to adversity or opportunities in terms of innovations during and following the crisis of the 1970s (see below). These industries reach a maximum average count of innovations in the periods 1975-1979 or 1980-1984. Figure 4.4 illustrates that the increase in the late 1970s and the beginning of the 1980s is sharply defined in terms of two separate increases. Intriguingly, the first increase taking place *during* the structural crisis, consisted mainly of traditional industries and traditional electronics equipment (e.g. home electronics and non-computer based industrial process control equipment). The second increase, slightly after the structural crisis, was in part carried by products linked to the microelectronics revolution.

Reaching a maximum average count during the structural crisis (1975-1979) were large parts of the machinery industry: agricultural and forestry machinery (SNI 293), machine tools (SNI 294), lifting and handling equipment (SNI 29220), cooling and ventilation equipment (SNI 29230) and other general purpose machinery (SNI 29240). Traditional electronic equipment such as office machinery (SNI 30010), industrial process control equipment (SNI 333) and domestic appliances n.e.c. (SNI 297, in which home electronics innovations are contained) were also reaching a maximum count of innovations during the structural crisis. Foodstuff, motor vehicles and some parts of the engineering industries also belong here (structural metal products and cutlery tools and general hardware). Reaching a maximum during the period 1980-1984 were computers (SNI 30020) and measuring instruments (SNI 332), as well as different types of special purpose machinery.

A second group of industries had secularly declining numbers of innovation throughout the period (having a maximum count of innovations in the first period, 1970-1974). These industries did thus not convey signs of response to the structural crisis in quantitative terms. Notably these industries were plastic products (SNI 252), electrical apparatus (all sub-categories of SNI 310 except electric motors, generators and transformers SNI 311 and accumulators, primary cells and primary batteries, SNI 314), and basic metals (SNI 270).

The third group of industries, shown in Table 4.4 and Figure 4.4, exhibit a marked increase throughout the period and/or an increase of innovations during the boom 1994-1999 or towards the end of the period studied. This group consisted *inter alia* of software and computer related services (SNI 720), telecommunication equipment (SNI 322 and 321), medical and surgical equipment (SNI 331), instruments and appliances for measuring (SNI 332), parts for motor vehicles (SNI 343) as well as pharmaceuticals (SNI 244). This group of industries thus can be well described as what has been called the ICT sector and the biomedical sector. It may be noted that

Figure 4.4: Main industrial patterns of innovation. Industries with declining counts of innovations (top) and industries with increasing counts (bottom).



Note: Industries have been grouped according to when the maximum count occurred. The count refers to the total of all industries in the group.

telecommunication equipment and optical instruments and photographic equipment peaked before or during the Telecom bust (2000-2002). A drastic decrease in telecommunication innovations occured during the Telecom bust. Telecom innovations (SNI 321, 322 and 323) decreased from 20 in 2000 to 7 in 2003. By contrast, software and medical surgical equipment innovations have increased throughout the period.

Table 4.2: Product groups with maximum counts during the periods 1970-1974 and 1975-1979.

Text	SNI	Count[a]	Period average[b]
Maximum 1970-1974			
Plastic products	252	154	7
Machinery for the production and use of mechanical power, except aircraft,	291	133	5.8
Basic metals	270	104	4
Electrical equipment n.e.c.	316	70	3.4
Machinery for mining, quarrying and construction	29520	48	2.4
Electricity distribution and control apparatus	312	43	2
Machinery for textile, apparel and leather production	29540	34	1.6
Bodies (coachwork) for motor vehicles; trailers and semi-trailers	342	18	1.6
Insulated wire and cable	313	13	0,6
Weapons and ammunition	296	12	0.4
Lighting equipment and electric lamps	315	11	0.6
Other transport equipment n.e.c.	355	6	0.4
Maximum 1975-1979			
Lifting and handling equipment	29220	198	8.2
Other general purpose machinery n.e.c.	29240	144	9
Machine-tools	294	144	6.4
Non-domestic cooling and ventilation equipment	29230	91	3.6
Food products and beverages	150	72	3.4
Industrial process control equipment	333	67	3
Cutlery, tools and general hardware	286	66	3.2
Agricultural and forestry machinery	293	58	4.4
Motor vehicles	341	56	2.6
Other chemical products (including soap and detergents etc and man-made fibres)	245-247	39	1.4
Structural metal products	281	39	2
Other non-metallic mineral products	260	38	2.8
Office machinery	30010	27	2.2
Domestic appliances n.e.c.	297	20	2
Furniture	361	13	1.2
Accumulators, primary cells and primary batteries	314	10	0.6
Recycling	370	10	0.6

[a] Total count of innovations over the period 1970-2007

[b] Period average. Industries are grouped according to the period at which the count of innovation culminates.

Table 4.3: Product groups with maximum counts during the periods 1980-1984 and 1985-1989.

Text	SNI	Count[a]	Period average[b]
Maximum 1980-1984			
Rubber products	251	42	2.2
Other fabricated metal products	287	72	3.6
Instruments and appliances for measuring, checking, testing, navigating and other	332	377	14.8
Building and repairing of ships and boats	351	39	2,2
Railway and tramway locomotives and rolling stock	352	13	1
Motorcycles and bicycles	354	13	1.4
Other business activities	740	118	7.4
Furnaces and furnace burners	29210	52	4
Machinery for metallurgy	29510	13	0.8
Machinery for food, beverage and tobacco processing	29530	30	1.8
Machinery for plastic and rubber processing	29561	13	0.8
Other special purpose machinery n.e.c.	29569	166	11
Computers	30020	220	9.4
Basic chemicals, pesticides and other agro-chemical products	241-242	55	2
Metal containers; central heating radiators; steam generators	282-283	24	1.6
Maximum 1985-1989			
Aircraft and spacecraft	353	15	4

[a] Total count of innovations over the period 1970-2007

[b] Period average. Industries are grouped according to the period at which the count of innovation culminates.

Table 4.4: Product groups with maximum counts during the periods 1990-1994, 1995-1999, 2000-2002 and 2003-2007.

Text	SNI	Count[a]	Period average[b]
Maximum 1990-1994			
Publishing, printing and reproduction of recorded media	220	4	0.4
Coke, refined petroleum & nuclear fuel	230	8	0.6
Machinery for paper and paperboard production	29550	39	2.4
Textiles, wearing apparel and leather	170-190	30	1.6
Maximum 1995-1999			
Paints, varnishes and similar coatings, printing ink and mastics	243	17	1.2
Electric motors, generators and transformers	311	34	2,2
Electronic valves and tubes and other electronic components	321	62	3
Television and radio transmitters and apparatus for line telephony and line	322	175	9
Parts and accessories for motor vehicles and their engines	343	74	3.8
Post and telecommunications	640	14	1.4
Maximum 2000-2002			
Pharmaceuticals	244	51	3
Television and radio receivers, sound or video recording or reproducing apparatus	323	51	2.67
Optical instruments and photographic equipment	334	67	3
Watches and clocks	335	4	0.33
Manufacture n.e.c	360A	19	2
Maximum 2003-2007			
Wood and wood products, except furniture	200	68	3.4
Pulp, paper and paper products	210	61	4.2
Medical and surgical equipment and orthopaedic appliances	331	85	3.8
Computer and related activities	720	224	16.8
Research and development	730	7	0.8
Forming and coating of metals; general mechanical engineering	284-285	22	1.23

[a] Total count of innovations over the period 1970-2007

[b] Period average. Industries are grouped according to the period at which the count of innovation culminates.

4.3.2 Creative response to problems and technological opportunities

The industry-level patterns observed suggest large increases of innovation both in traditional industries and in new industries, ICT in particular. The next question is what driving forces may explain the observed patterns of innovation. Can the increase of innovations be explained by the creative response to technological opportunities or techno-economic problems and adversity? This section introduces the basic results as regards the role played by negative and positive factors in innovation activity.

As explained in chapter 2 innovations that respond to *positive transformation pressure* are in this thesis defined as innovations that exploit new *technological opportunities* or solve a special kind of problem, *technological bottlenecks*. Two major technological shifts took place during the period studied. The opportunities of the micro-electronics revolution and the diffusion of Internet technologies can be expected to have had a thorough impact on innovation activity. Moreover, biotechnology has had an impact in pharmaceutical, measuring instruments and other industries such as foodstuff. Therefore these two categories of technological opportunities are specifically studied. Technological bottlenecks are techno-economic problems that hinder the exploitation or use of a *new* good, material or technology. Though being a kind of problem, innovating firms that responding to these kinds of problems are understood as acting under a positive transformation pressure.

Negative factors are defined in terms of three types of problems:

1. *Induced*. Obstacles to the rational production, transportation or use of a good and obstacles to the replacement of an inferior, or otherwise undesirable, good. This includes irrational costs, such as spill and leakages, unprofitability, and cases of factor price induced innovation.

2. *Organizational*. Innovations responding to techno-economic obstacles to the fulfilment of organizational goals (e.g. in the working environment).

3. *Environmental*. Techno-economic obstacles to the reduction or handling of negative production externalities, such as emissions or waste

Other problem-solving innovations, for instance innovations solving technical measurement problems have been classified as miscellaneous problem-solving innovations.

The results are summarized in Tables 4.5-4.7 and Figures 4.5-4.8. Innovations that have cited positive transformation pressure was the largest category, corresponding to 47.92% of the total count of innovations. Negative transformation pressure influenced 25.78% of the total number of innovations. 329 innovations cited both positive and negative factors. The remainder (34.25%) found their driving forces elsewhere, typically developed to improve the performance of a product, or being the result of institutionalized search for new products and large-scale innovation projects.

It is the negative and positive factors that shape the particular pattern of innovation observed in the Swedish manufacturing industry. Figure 4.5 shows that the increase during the structural crisis and the 1990s are entirely accounted for by innovations that cite technological opportunities or techno-economic problems. Innovations citing neither positive or negative factors display a flat decreasing pattern and cannot account for the sharp alterations in the count of innovation previously observed.

The count of innovations citing positive and negative factors are displayed in Figure 4.6.[3] This figure shows first and foremost that innovations driven by a positive transformation pressure has followed a particular pattern of two major increases. A first increase took place from 1970, culminating about 1983 (with five year centered moving averages). A decline followed until the crisis of the 1990s. From the trough innovations increased anew during the boom of the 1990s until the onset of the Telecom crisis. After 2000 the count of innovations was stable. Table 4.6 and Figure 4.7 breaks down the major sources of positive transformation pressure. The broad opportunities that could be classified as ultimately stemming from the micro-electronics revolution were seemingly ubiquitous, accounting for most of the positive factors. Of 1984 innovations citing positive transformation pressure, 1379 exploited information and telecommunication technologies. A smaller share was accounted for by biotechnology (88 innovations). Technological bottlenecks were 381 in total during the period. For the most part these were also ICT innovations, ultimately exploiting microelectronics.

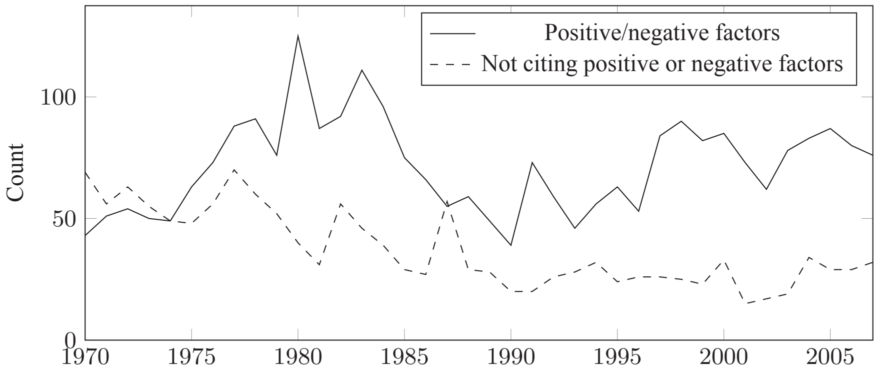
Innovations citing negative transformation pressure were by and large concentrated to the structural crisis of the 1970s. This is shown in Figure

[3] There is, as shown in Table 4.5, a minor overlap between innovations citing positive and negative factors. This overlap is not shown in Figure 4.6. The overlap does however not alter the pattern over time or the results.

Table 4.5: Count of innovations citing positive and negative transformation pressure.

	1970-1989	1990-2007	1970-2007
Positive	905	1079	1984
Negative	722	345	1067
Overlap	174	155	329
Not citing negative or positive factors	960	458	1418
Total database	2413	1727	4140

Figure 4.5: Count of innovations responding to positive or negative factors and innovations citing neither positive nor negative factors, by year of commercialization 1970-2007.



4.5. This pattern of creative response culminated during the late structural crisis, roughly in 1979 (using five year centered moving averages). Innovations responding to obstacles to the rational production, transportation or use of goods, as well as environmental innovations were important in explaining the increase. Table 4.7 and Figure 4.8 breaks down the major sources of negative transformation pressure. During the period 430 innovations cited economic, 433 cited environmental and 204 cited organizational problems. All of these innovations were by and large concentrated to the structural crisis. There was also a smaller increase in innovations responding to negative factors during the 1990s, e.g. automotive innovations responding to emission control regulations and renewable energy technologies (see also Chapter 6).

Figure 4.6: Count of innovations responding to positive factors (left) and negative factors (right).

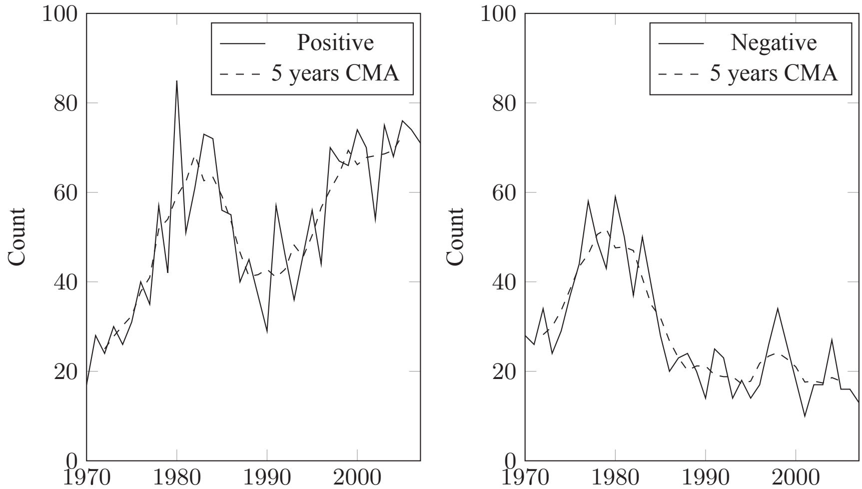


Table 4.6: Count of innovations citing positive transformation pressure. Technological opportunities and technological bottlenecks.

	1970-1989	1990-2007	1970-2007
Technological opportunities	829	1050	1879
of which exploit:			
Information and telecommunication technologies	505	874	1379
Biotechnology	39	49	88
Other technologies	285	131	412
Technological bottlenecks	169	212	381
of which overlap with ICT	54	155	209
of which overlap with other opportunities	39	28	67
Sum Total	905	1079	1984

Table 4.7: Innovations citing negative transformation pressure, and other problem-solving innovations

	1970-1989	1990-2007	1970-2007
Induced	305	125	430
Organizational	138	66	204
Environmental	279	154	433
Sum Total, negative factors	722	345	1067
Miscellaneous problem-solving innovations	76	61	137

Figure 4.7: Count of innovations citing positive transformation pressure, by sub-category, 1970-2007.

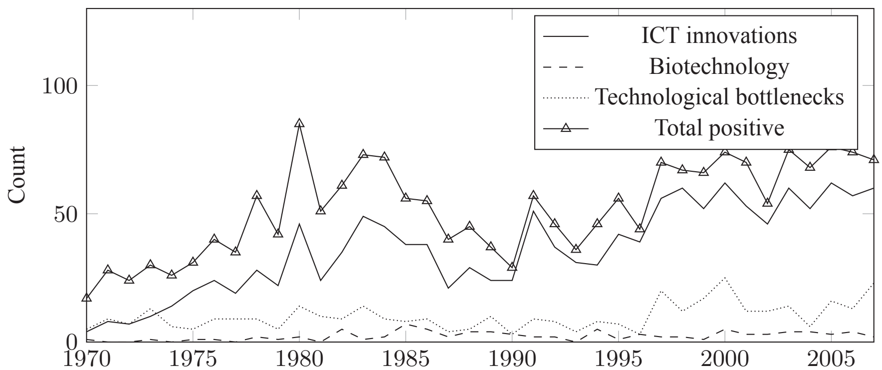


Figure 4.8: Count of innovations citing negative transformation pressure, by sub-category, 1970-2007.

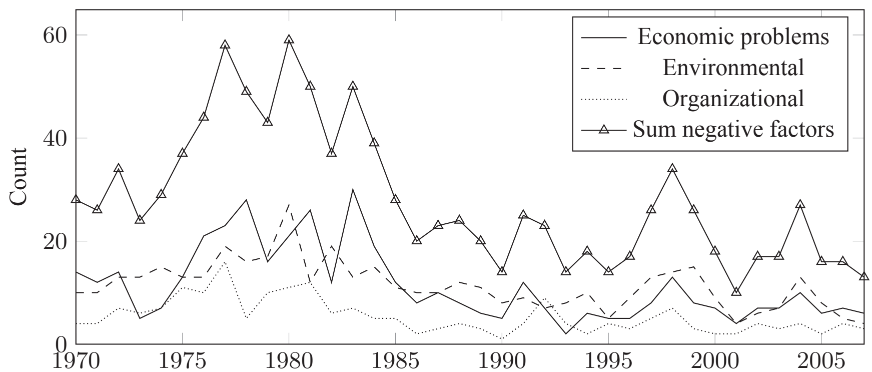


Table 4.8: Tests for overdispersion and surges in positive and negative patterns of creative response

	Negative	Positive
(1) Years above period average (P<0.10)	1976-1984	1980; 1983-1984; 1997-2001; 2003-2007
(P<0.01)	1976-1981; 1983	1980; 1983-1984; 2000; 2003; 2005-2007
(2) Years above average since the last surge (P<0.10)	1976-1978	1978-1984; 1991; 1995; 1997-2001
(P<0.01)	1977	1978; 1980; 1982-1984; 1997-1998; 2000
α	0.078 [0.026]	0.056 [0.018]
χ^2	45.44^{***}	51.76^{***}

Note: *, p<0.1; **, p<0.05; ***, p<0.01. Standard errors in brackets.
α tests the null-hypothesis that the conditional mean $\mu = E(Y|t)$ of a Poisson regression is equal to the variance $Var(y)$. The parameter α is obtained by estimating $Var(y) = (1 + \alpha) \cdot \mu$. The Poisson regressions tested include a trend estimation.

4.3.3 Surges in the count of innovations

The major increases observed in the pattern of innovation can be analyzed more formally. Drawing on the literature on clustering of innovations, a "surge" can be given a formal definition as years in which values in the count of innovations have exceeded the expected count on standard levels of significance. The issue is of course how to define the expected count. Previous research has stressed that count data frequently cannot be expected to be normally distributed, but rather following a Poisson (equidispersed) or negative binomial distribution (overdispersed) (Blundell et al., 1995; Silverberg & Verspagen, 2003; Cameron & Trivedi, 2005). Silverberg & Lehnert (1993) and Silverberg & Verspagen (2003) have suggested that the null-hypothesis of a non-clustering process is that innovation counts are Poisson distributed.

Following Cameron (1990) and Cameron & Trivedi (2005), tests of the null-hypothesis that the mean of the process equals the variance were carried out. The results, reported in Table 4.8, reject the null-hypothesis of a Poisson distributed non-clustering process. Thus there may be years in our time series that reflect clustering of innovations. A surge is then possible to define as those years in which the count of innovations have exceeded the expected count with standard levels of significance according to the Poisson distribution. Table 4.8 reports years when the count of innovations was significantly ($P<0.10$) above the period average (1) and above the average count since the last surge (2). The former definition compares the count of innovations to a fixed period average. This may define surges, but it is biased in the opposite direction of the trend of the time series. If the trend is negative, it may find surges in the first period and vice versa. The second definition allows surges to be defined relative to the average of the previous count of innovation. This definition is however biased towards finding surges in which the count increases rapidly. Both methods thus have drawbacks but together they may point us towards years of culmination of a surge. Years in the pattern of innovations citing positive factors that were significant in *both methods* occurred in 1980, 1983-1984 and 2000 ($P<0.01$). Using the broadest significant periods found, the suggested surges then have taken place in 1978-1984 and 1997-2001 at most, culminating in the years 1983-1984 and 2000 respectively. The culmination of a surge among innovations citing negative factors appears to have been in 1977. The most comprehensive surge period is then 1976-1984, with an early culmination in 1977.

4.3.4 Innovation, business cycles and the structural cycle

The patterns previously observed inform us of two surges of innovation: an increase in the count of innovation taking place during and following the structural crisis and an increase taking place after the crisis of the 1990s. The analysis of the industry composition and the negative and positive factors behind the surges may now be contrasted with the accounts of business cycles and the structural cycle that were reviewed in section 4.2.3. The first surge in innovation activity took place during and following the structural crisis of the 1970s. This surge resulted both from the diffusion of ICT technology and a negative transformation pressure. Negative factors however appear to have been a more important factor early in the crisis, i.e. 1975-1979, whereas ICT innovations peaked in 1983. Industries that to a large extent accounted for the early increase were lifting and handling equipment (SNI 29220), other general purpose machinery (SNI 29240), machine tools (SNI 294), and cooling and ventilaition equipment (SNI 29230). Industries that accounted for the later increase in the early 1980s were instrument and appliances for measuring (SNI 332) and computers (SNI 30020).

The second surge took place during the boom of the 1990s predominantly carried by telecommunication and software innovations (SNI 321-323 and SNI 720) and the biomedical industries (SNI 244 and SNI 331). The importance of negative factors in innovation activity decreased from the structural crisis throughout the period. Negative factors thus did not contribute to any great extent to the surge in 1995-2007.

Whereas innovation activity during and following the structural crisis was ample, this cannot be said about the transformation crisis (1990-1994). The transformation crisis rather marks the bottom count of innovations in the database. While the count of innovations driven by a positive transformation pressure culminated during the Telecom bust, the crisis itself rather led to a decrease in the count of telecommunication innovations. These broader results do not seem to support a view of the launching innovations as being either pro- or counter-cyclical. The results rather suggest that innovation patterns are determined by factors that transcend the short-term business cycles. Different forces may be at work in different crises and expansions that may produce different patterns of creative response. In particular, there are similarities between the pattern of innovations citing positive transformation pressure and the Kuznets cycle (or long swing) of roughly 15-25 years of duration. Conversely, the pattern of innovations that respond to negative transformation pressure may be explained by the appearance of structural imbalances during the crisis of the 1970s. To further examine the qualitative content of these patterns, it is suitable to turn to an analysis of the 'how' of creative response.

4.4 Explaining patterns of innovation

The remainder of this chapter is devoted to *describe* the previously found surges in innovation in terms of the actual innovations, the positive and negative factors involved and the industries which have played a pronounced role in the surges. What were the problems and opportunities that motivated innovations? In what industries?

In sections 4.4.1 and 4.4.2 the positive and negative factors behind the surge during and following the structural crisis are described and analyzed. It is argued that the surge in innovation activity during and following upon the structural crisis can be entirely explained by two factors: a) the accelerated automation and computerization of machinery equipment during the

1970s and the 1980s following from the third industrial revolution, b) creative response to adversities in the form of techno-economic problems, pressure to deal with negative externalities, waning demand or unprofitability. In section 4.4.3 the, factors behind the increase in innovation activity during the period 1995-2007 are discussed. It is argued that the surge in innovation activity can be explained by the wider diffusion of ICT technologies, most notably in telecommunication equipment and software, and biotechnologies. Moreover, the section 4.4.1 indicates that large corporate groups, such as Asea and Saab were instrumental in the early microelectronics revolution, whereas many firms in the latter surge were small entrant firms.

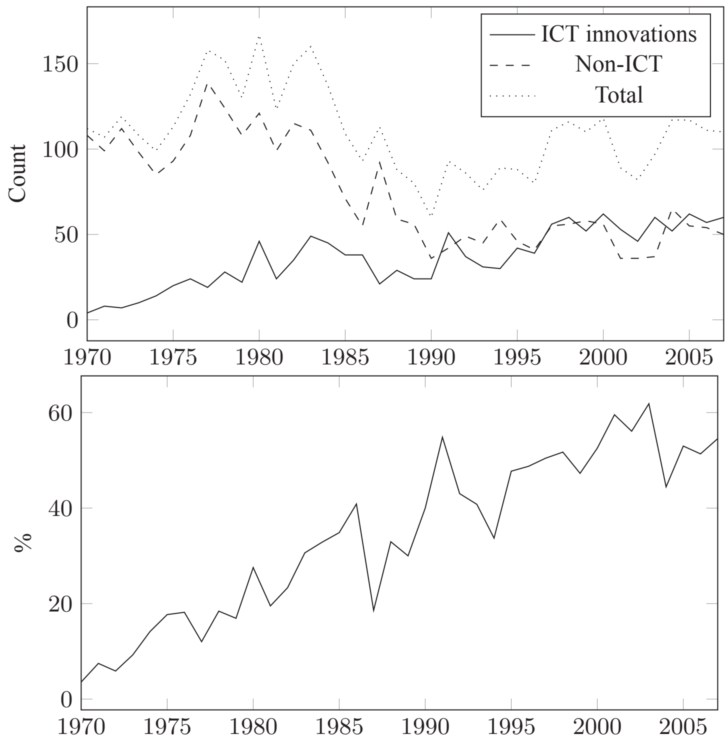
4.4.1 The surge carried by the third industrial revolution

The number of innovations during the 1970s and 1980s that were *users of micro-electronics*, i.e. exploited minicomputers, microprocessors, laser technology, computerized numerical control systems and computers, gives support to the view that a significant role was played by opportunities brought forth by the microelectronics revolution. These innovations make up a great portion of the surge in the period 1975-1984. The count of ICT innovations increased until 1983 in absolute counts but the share of ICT innovations developed in the database has increased steadily from the beginning of the period. This is shown in Figure 4.9.

As opposed to the later half of the period (see section 4.4.3), ICT innovations during the 1970s and 1980s were largely focused on industrial applications and *factory automation*. The activity centered around ICT innovations in Sweden during the 1970s and the 1980s has been understood as a development block composed by the development of control systems, computer controlled machinery, automation equipment and automatic guided vehicles (Carlsson, 1995; see also chapter 6). The below paragraphs briefly describe these components of the macro-development block surrounding ICT innovations.

The diffusion of microprocessor based technology enabled new generations of machinery and instruments for control and measurement with improved performance. At the core of this development lay control systems (SNI 333) and computer equipment (SNI 30020). Numeric Control (NC) systems had already been introduced into machinery during the course of the 1960s, but predominantly among large firms. Asea was one the pioneers of the development of commercially available Computer Numeric Control

Figure 4.9: Count of ICT innovations and Non-ICT (top) and share of ICT innovations in total, 1970-2007 (bottom).



systems (CNC) with its introduction of Nucon 1972 and Nucon 400 in 1977 (*Ny Teknik* 1972:3, p. 4; *Verkstäderna* 1977:4, p. 90). The introduction of such computerized numeric control systems decreased significantly the set-up costs involved in changing product models thus enabling a greater degree of flexibility. Flexibility became an increasingly important factor in technological development. Before the 1970s so-called PID-regulators were used but were considered unsatisfactory as they could not deal with processes whose properties change over time. Asea, aided by scientific advances made at Lund university, started development of a microcomputer based general system that was self-adaptive, and launched the first self adaptive control system in the world in 1982, called Novatune (*Automation* 1982:4, pp. 19-20; 1984:3, p. 60; 1984:5, pp. 11-12, 14-15; *Jernkontorets Annaler* 1982:3, p. 53; *Verkstäderna* 1982:11, p. 56). The experience from Asea's universal process control products DS 8 and PLC 700 had shown that the necessary engineering expertise for application was often specific. A modularised system was therefore developed and launched in 1982 under the name 'Asea Master' allowing flexible application with a minimum of specific engineering expertise (*Modern Elektronik* 1983:8, pp. 26-29; *Automation* 1985:2, p. 3; *Elteknik* 1986:18, pp. 30-32; *Svensk Papperstidning* 1990:7, pp. 77-79).

Despite the development and diffusion of computerized control systems, there are only few examples of traditional machinery innovations that were based upon *integrating* them during the 1970s. Only three of the machinery innovations introduced during the 1970s were mentioned to be NC or CNC controlled (SMT Machinery AB’s Swedturn 18 and Swedturn 20 and AB Torshälla's TMC-53H CNC). Among the innovations contained in the SWINNO database, the exploitation of microelectronics in machinery innovation rather takes expression in the sizeable number of industrial robots developed by Swedish firms and in machinery innovations taking advantage of minicomputers, computers or image processing equipment. Swedish firms lay at the forefront of the development of robots. ASEA Robotics (ABB Robotics after 1988) was a market leader in this field, launching several notable robot innovations during the period studied. ASEA’s IRB 6 launched in 1973, was the first wholly electrical microprocessor controlled robot commercially available (Glete 1983, *Modern Elektronik* 1986:16, pp. 47-49). ASEA began research and development in 1977 of a new robot system based on computer based image processing technology. The result, "ASEA Robot Vision", was commercialized in 1983 (*Ny Teknik* 1983:37, p. 3; *Verkstäderna* 1983:13, pp. 44-46). Other early industrial robot innovations were developed by e.g. R Kaufeldt, an engineering firm, Retab AB and Electrolux. In 1969 Electrolux decided to start its own industry robot program. The decision resulted in a modular robot (called MHU, Material Handling Unit) designed for material handling, launched in 1971. A palletizer robot was launched in 1980 based on the MHU system.[4] Retab AB launched a tool carrying industry robot "Coat-A-Matic" that was developed in collaboration with Hiab-Foco AB. R Kaufeldt's early robot "A3" was wholly pneumatic (*Transport Teknik* 1971: 9, pp. 456-7) whereas later industry robots involved the development of micro-processor based control systems (*Automation* 1977:3, pp. 14-15). Spurred by the shipbuilding crisis, the shipbuilding company Kockums diversified into manufacturing robots, launching a picking robot used *inter alia* in the book binding industry (*AGI* 1979:73, pp. 30-31; 1979:79, p. 28; 1982:104, p. 46; *Automation* 1979:8, p. 35).

Automated guided vehicles (AGV) was another important component of the factory automation development block. Large firms, in particular in the automative industry were early on active in developing automated guided vehicles. In the beginning of the 1970s there were techno-economic hinders to the introduction of automated guided vehicles, but recent progress had made AGVs possible in rail traffic. The two large firms, Saab-Scania and ASEA had collaborated to develop systems for the automation of mining transports (*Transport Teknik* 1971: 6, pp. 280-1; *Modern Elektronik* 1971-12 p. 11). Volvo developed a carrier technology technology in the first half of the 1970s. A subsidiary, ACS (AutoCarrier System) was created, later sold to BT Industries that continued to develop automated guided vehicle innovations (Elsässer 1995, p. 167; *Automation* 1978:7, pp. 32-34; *Verkstäderna* 1977:13, pp. 43-5). AutoNavigator AB and Luleå University of Technology developed a laser navigator aimed to enable AGVs without guideways, thereby overcoming obstacles to attaining more flexible installation (*Automation* 1990:1, pp. 13-15; *Ny Teknik* 1992:45, p. 14; 1992:45, p. 16; 1989:40, p. 6; *AGI* 1991:204, p. 66).[5]

[4]In 1981 Electrolux robot division was merged with ASEA Robotics. The production of MHU robots was later cancelled, but another firm, MHU Robotics continued to develop MHU robots.

[5]"When the driverless trucks showed up a couple of decades ago, the flexibility was an important argument. They needed now "only" a rail in the floor. However, with increasing demands for flexibility in production guideways have proven expensive and a hassle, especially if you subsequently want to modify and extend the trucks' movement patterns. [---] When researchers at the University of Technology five years ago came up with a laser navigator they saw a solution to the problems, the truck could be both easier to install and more

One may notice that several mentioned examples were innovations developed by large corporate groups, Asea, Saab-Scania, Electrolux and Volvo. The role played by these large firms in the development block surrounding ICT technology during its early stages has been highlighted by others (Carlsson, 1995). During the 1980s innovation activity in ICT was however increasingly carried out by smaller and younger firms observing market niches or technological imbalances (see chapter 6 for a further discussion). Several new firms were developing robots and auxiliary parts for robots. Other firms were exploiting robot innovations and integrating robots in manufacturing systems. Best-matic started development of a robot-based waterjet cutting system (*Modern Elektronik* 1989:2, p. 63; *Verkstäderna* 1991:3, pp. 56-58). Towards the end of the 1980s computer aided design (CAD) and computer aided manufacturing (CAM) innovations were developed by Swedish firms, exploiting previous advances. For instance, Esab Robotsvetsning developed a Flexible Manufacturing system based on Asea's IRB 90 and Asea Master (*Automation* 1987:1, pp. 11-12; *Ny Teknik* 1987:45, p. 37). Ortic developed a CAD/CAM system for rational production of roll forming tools (*Jernkontorets Annaler* 1986:2, pp. 14-16). Torsteknik AB developed a Flexible Manufaturing system (FMS) (*Automation* 1987:4, pp. 20-2, 30). Other small firms were developing computers. Examples of actors in this surge were smaller firms such as Mydata AB, one of the first Swedish firms to develop computers – one called M4-15 (*Elteknik* 1976:12, pp. 6-7) and an education purpose computer MY-15 - built on microcomputers from Intel, both launched in 1976 (*Modern Elektronik* 1975:20, pp. 29-31; *Automation* 1976:2, p. 38). At the time however the market for desk computers was small and the company only gained financial success with Logpoint (1981), a system for the assembly of components on integrated circuits. Other small firms in the database that launched computer innovations during this period were specialized and directed towards narrow industries (examples are power plants and fishing industry). Sweden’s first personal computer called ABC 80 was launched on the Swedish market in 1978 and had been developed by the three Swedish companies Luxor Industri AB, Scandic Metric AB and Dataindustrier AB (later DIAB) to meet the difficulties arising from a saturated market in home electronics (TV and audio systems). The follow-up personal computers were Scandic Metric AB’s Metric 85 (1980) with

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user friendly. Through the Luleå company AutoNavigator and inventor Kalevi Hyyppä a collaboration was initiated to adapt the technology to AGVs (Automatic Guided Vehicle)" (*Automation* 1990:1, pp. 13-15, translation by the author).

greater capacity (*Automation* 1980:4, pp. 41-42) and ABC 800 (*Automation* 1980:1, p. 42; *Ny Teknik* 1981:12, pp. 8-9; *Verkstäderna* 1981:5, p. 40).

4.4.2 Negative transformation pressure during the crisis of the 1970s

While the preceding results indicate that the surge after the structural crisis to a sizeable extent resulted from the application of micro-electronics in machinery, and the development of computers and electronic equipment, it is imperative to note that these results cannot entirely explain the surge centered *during* the structural crisis. Instead, this surge can be explained by the various sources of negative transformation pressure that emerged from the end of the 1960s and was accentuated during the structural crisis. In Figure 4.8 the counts of ICT innovations and innovations responding to negative transformation pressure are displayed. The increase observed was carried by innovations responding to three types of problems: a) *environmental problems* from industrial production, e.g. waste and emission, b) *organizational problems*: techno-economic problems involving the work environment, and c) *economic*: obstacles to the rational production, transportation or use of goods. The below sections aim to describe and shed light on the historical processes leading to this wave of creative response.

The sources of the creative response during the structural crisis lay thus both in problems accentuated due to the oil and energy crisis and in waning demand and profitability. Problem-solving innovations were during the 1970s the creative response to several generic problems associated with the energy crisis, the oil crisis, the situation developing from a Swedish shortage of wood, and the increased awareness and political pressure to reduce pollution and industrial waste in the chemical, paper and pulp and the forestry industries. Moreover, several industries faced issues related to the working environment that motivated technological development during the 1970s, some of which were negative externalities afflicting the working environment (asbesthos and toxic gases), others e.g. occupational noise and work related injuries.

4.4.2.1 Environmental problems and negative externalities

The SWINNO-database reveals an increased response to problems that involve environmental problems during the structural crisis of the 1970s. This can be observed in Figure 4.8. The 1970s has been described as a breaking point in several ways as concerns environmental policy and the actual evolution of energy consumption and emissions. Kander (2002) and Kander & Lindmark (2004, 2006) have shown that energy consumption and pollutant emissions in Sweden increased in absolute terms up until 1970, after which energy consumption stabilised and emissions decreased. This research also suggests that declines in energy consumption and pollution after the 1970s can been attributed to technical change. The results of the SWINNO database corroborate the view that the crisis of the 1970s motivated efforts to save energy and deal with negative externalities, such as air and water pollution, but also to replace the use of fossil fuels.

It is possible to point to several factors behind the increased number of innovations aiming to solve environmental problems, some of which are rooted in political and institutional changes stemming from the beginning of the 1960s and some of which are more directly linked to the oil and energy crisis. The creative response to environmental problems can in part be explained by an increased social and political awareness of environmental issues that emerged in the 1960s. Resulting from this political process, the Swedish Environmental Protection Agency (Naturvårdsverket) was formed in 1967 and Sweden's first environmental protection law, the Environmental Protection Act was introduced in 1969. The environmental policy aimed to establish consensual agreements with each production unit based on what was technically and economically feasible, and environmentally desirable. Emission standards were negotiated at the industry-level. At this time, an increased focus had in particular been brought to water and air pollutions, resulting in the formation of the Swedish Environmental Research Institute (IVL) in 1965 (Bergquist & Söderholm, 2011).

This may explain that a comparatively large number of innovations were developed in the beginning of the 1970s, i.e. before the oil crisis, with the aim to handle production externalities. In particular, machinery and process innovations were developed to deal with water and air pollution in the pulp and paper, chemical, engineering and steel industries. Uddesholm (*Kemisk Tidskrift* 1973: 12, pp. 58-63), Avesta Jernverk (*Bergsmannen med modernamaterial SJM-bulletin* 1972:10, pp. 222-225; *Kemisk Tidskrift* 1973:1-2, p. 14) and Gränges (*Ny Teknik* 1971:20, p. 4) were examples of steel companies that had initiated search for solutions for their own toxic waste problems in the 1960s.

Chemical separation processes were developed to solve the handling of water pollution, for instance heavy metals from steel plants. One example is the science-spinoff firm MX-processer that in 1973 started their development of liquid extraction processes to recycle metals from mordants resulting in several innovations (*Ny Teknik* 1976:15, p. 13; 1977:31, pp. 16-17). In the late fall 1974, the Swedish State Power Board (Vattenfall) asked MX-processes to solve their problems with the handling and storage of soot waste. MX-processer therefore started the development of a new process based on their technology of liquid extraction, aimed to extract heavy metals vanadine and nickel from soot and ashes. This eventually lead to the starting of a new company, SOTEX AB, which with the financial support of the Swedish Environmental Protection Agency (Naturvårdsverket) developed a recycling facility for Vattenfall (*Kemisk Tidskrift* 1978:3, p. 17).

While thus some development projects already were started before the crisis, the energy and oil crisis of the 1970s intensified or spurred the search for new energy sources as well as alternative fuels and other attempts to reduce oil dependency. The energy use of the Swedish industry shifted during the 1970s and 1980s from oil to electricity, district heating and biofuels. Biofuels have from the 1990s become increasingly important (Kander, 2002). A large number of innovations were the creative response to these challenges: heating pumps for district heating (see chapter 5 and 6) and various new technologies for the use of methanol for engines, coal, peat and biofuels such as wood, forest and pulp residue.

The search for alternative fuels can be described as induced by both the high energy costs and political pressure. Following the oil crisis, Sweden's first government bill considering energy policy was issued in 1975. The new bill contained an alternative fuel strategy. Attempts to replace oil were initially directed towards other fossil fuels for energy production and methanol for engines. At the time coal was broadly thought to replace oil, and the market share of coal increased during the first half of the 1980s (Kander, 2002). This is reflected in several innovations. Coal was attractive in terms of its price, but a transition to coal however faced techno-economic and infrastructural problems pertaining to the handling and transportation of coal as it is apt to self-combustion and dusting. AB Scaniainventor, owned by the Swedish concern Boliden, responded to the oil crisis by initiating search for a coal based alternative to oil, resulting in a system called "Carbogel" (*Jernkontorets Annaler* 1980:4, pp. 41-42; *Ny Teknik* 1973:5, p. 10; 1980:28, p. 4).[6] Aimed towards the metallurgic industry another company,

[6]"In Sweden's future, coal will increasingly need to replace oil and probably even nuclear power. Coal of commercial quality containing ash, sulphur and heavy metals which pose considerable disadvantages in coal handling and fuel compared to oil. Coal dust, oc-

a fuel called "Murf" (Multiuse rational fuel) was developed by Sedico Energy AB as an alternative coal-based fuel, that could overcome some of the major problems with coal, e.g. self-combustion and dusting (*Jernkontorets Annaler* 1979:4, pp. 31-32).

Methanol came to dominate the research efforts for alternative fuels for engines during the 1970s and the 1980s. The development of alternative fuels received an institutional infrastructure through the governmental energy research programme started in 1975. Research was primarily centered on methanol (Sandén & Jonasson, 2005). Several processes and products were developed to enable domestic production of methanol. Studsvik, a former nuclear research company, funded by the research programme, for instance developed a process called MINO that enabled production of methanol from peat or biomass (*Ny Teknik* 1983:35, p. 8).[7] The automotive companies Saab-Scania and Volvo each developed methanol engines, commissioned by Swedish Drivmedelsteknik AB. Efforts were particularly made to overcome the techno-economic problems with methanol, such as the risk of knocking at high speed (*Ny Teknik* 1982:4, p. 4).

Other innovations were developed to enable the use of peat and biofuels, such as wood, forest and pulp residue. These technologies have meant a more radical break from oil-based production systems, but have also struggled with more formidable obstacles (see also chapter 6). Several innovations in the SWINNO database were developed aiming to overcome techno-economic obstacles to the use of various forms of bio-energy, e.g. from forest residue, peat and recycled biological waste. Vyrmetoder developed a method to extract methane gas from peat *in situ*. A problem was that

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cupying large areas in normal handling and lacks infrastructure for use on a large scale. Development work abroad and in Sweden aims to clarify these problems and present solutions. This is important because coal is the mineral raw material that is foreseen to have the strongest development and market potential over the next next 20 - 30 years. [---] As a major energy consumer, Boliden has always been involved in energy production. Given the recent trend Boliden has been trying to use their special skills in all areas of the energy sector. [---] Since the first oil crisis 1973 the innovation company AB Scaniainventor in Helsingborg has worked with transforming coal to liquid fuel. The goal has been to develop a coal based alternative to oil. The development has resulted in the interesting Carbogel system. One of the central parts of the Carbogel idea is that coal can and should be purified at the earliest possible state in the coal treatment process. [---] With Carbogel many of the environmental drawbacks with conventional coal burning are eliminated" (*Jernkontorets Annaler* 1980:4, pp. 41-42; translation by the author).

[7]Studsvik had early on studied the possibilities of carbon and was also active in developing technologies for converting long-distance heating furnaces to fuelling with coal powder.

other methods for extracting methane gas were damaging for the environment (*Ny Teknik* 1981:42, p. 11). Innovations were also developed to enable profitable use of combustible wood materials such as branches and tree tops. A number of innovations were also developed to enable the gasification of pulp and paper residue, an area in which Swedish firms have been prominent (see chapter 6).

Another set of innovations were aiming primarily to reduce energy costs in the face of rising relative prices of energy. These have been classified as being "induced innovations" responding to economic problems (see below), but are better dealt with in the context of the energy crisis. The energy price chocks had in particular an observable impact on innovations relating to energy distribution, such as ventilation apparatus, heating radiators, or ship and automotive engines. An example is Stal-Laval Turbin AB, a turbine manufacturer and one of the pioneers in the development of turbine powered ship engines. When Stal-Laval Turbin developed AP (Advanced Propulsion), launched in 1965, there was no interest in lowering the fuel consumption due to low oil prices. The firm's next product, VAP (Very Advanced Propulsion) a steam propulsion, turbine plant, began development in 1975 under the influence of the oil and energy crisis. Attempts were now made to attain fuel economy and make possible the utilization of various fuels, mainly coal and oil. By using fluidized bed technology a first step was taken to replace oil based fuels (*Verkstäderna* 1982:3, pp. 21-23).[8] Stal Laval was in general adversely affected by the oil price increases, forcing it to examine alternative energy sources and to diversify into heating pumps (Glete, 1983, p. 289; *Ny Teknik* 1982:41, p. 41; *Verkstäderna* 1982:12, p. 21-23; see also chapter 6).

4.4.2.2 Innovation and the work environment

Another set of problems pertaining to the working environment were paid increased attention during the 1970s and drove numerous innovation processes. These problems have been labelled 'organizational' as they concerned occupational safety or the in-house factory or firm working environment and need to be separated from the broader environmental and energy problems. Several of these organizational problems however also pertain to

[8] "When we began in 1975 to develop VAP system fuel economy was the essence, says sales manager Per Erik Larsson at the Navy Department. One condition was improved thermal efficiency through a more advanced steam cycle with reheat and high steam data. Another condition is improved efficiencies of the components in the main engine and auxiliaries" (*Verkstäderna* 1982:3, pp. 21-23; translation by the author).

negative externalities from industrial processes and production.

Historical research on the Swedish work environment has characterized the 1970s as a period of great change in policy and as a period in which demands for work environment improvements were met by employers (Lundh & Gunnarsson, 1987; Berggren & Olsson, 1988; Thörnqvist, 2005). During the post-war period, work environment measures were regulated in centralised agreements between the labor unions and employers organisations. Focus was placed on reducing work place accidents, while other problems, for instance occupational diseases, were not given the same amount of attention. A broader political awareness of these issues was stirred in the early 1970s that led eventually to The Work Environment Act, passed by the Swedish parliament in 1977.

This development was also related to social conflict. The end of the 1960s and the 1970s saw a rise in social conflicts and labor militancy that added urgency to political and organizational responses. Social conflicts were for the most part concentrated to "old" industries of Fordist mass production, internationally as well as in Sweden (Thörnqvist, 1994).

An important event was the miners strike in LKAB 1969-1970 that concerned the working environment, and had implications on the work-environment debate (Alalehto, 1992). The mining strike was triggered by discontent with piece wages. Higher wages and a replacement of piece wages with monthly wages were demands advanced during the strike. The strike was however in part also a reaction to the advert working environment problems that resulted from an increased mechanisation carried out by LKAB during the 1960s. The major environmental problems were work place accidents, diesel exhaust and poor ventilation capacity, but also vibrations from drilling machines and occupational noise (Alalehto, 1992, pp. 96-100). While the main short term measures taken by LKAB were to search for new labor-saving methods to enable increased mechanisation, other firms developed innovations aimed to appease the work environment in the mining sector. Some were launched shortly after the strike. Atlas Copco, a major supplier of rock drilling equipment, for instance developed a dust collector to decrease the problems with dusting in rock drilling (*Bergsmannen med moderna material SJM-bulletin* 1972:6, p. 149). Saab-Scania's first automatically controlled unmanned vehicle was developed as a mining truck due to the apparent need to improve the working environment (*Transport Teknik* 1971:6, pp. 280-1). LKAB launched the "Kiruna bolt" in 1970 (*Ny Teknik* 1970:20, p. 10), a rock bolt developed to solve the problems with collapse risks and work-related injuries in mining operations.

Over the following years, LKAB, other mining companies and subcontractors made several similar innovations, as the use of large scale mining methods had led to increasing problems with failing rock strength (*Ny Teknik* 1981:5, pp. 12-13). For instance, in April 1975, there was a rock movement in LKAB's Kiruna mine that necessitated a new method to reinforce rock excavations (*Ny Teknik* 1978:12, pp. 16-17). Boliden, another mining company, had experienced increased problems with misfired rounds and accidents in rock blasting and contracted an electronics firm (Tri Electronics) to solve the problem. This resulted in the development of a new ignition system for rock blasting (*Ny Teknik* 1975:20, p. 13). Pneumatisk Transport AB developed a device that allowed the mechanization of the charching of explosives to avoid the previously large risk of rock collapse and heavy manual work (*Ny Teknik* 1977:35, p. 30). Similar experiences led to joint development of the Swellex product line: steel pipe products aimed to reinforce roofs and walls in mines and in underground constructing sites (*Ny Teknik* 1981:43, p. 24; *Jernkontorets annaler*, 1981:5, p. 53; *Bergsmannen med Jernkontorets Annaler* 1996:1, pp. 43-44).

The engineering and construction industries had work-related problems with occupational noise, injuries from vibrations in drilling operations, and the engineering industry also had problems involving toxic welding gases.

Development efforts were also made in order to deal with the adverse health effects of organic solvents in the plastic, graphic and chemical industries. Research institutes (Arbetarskyddsfonden and Arbetslivscentrum) were established to develop improvements to the problem with organic solvents. Styrene, a hazardous chemical, was a problem to the plastic industry, which motivated several innovations during the 1970s and 1980s.

During the latter part of the 1960s studies had shown that the risk for pleural cancer was higher for asbestos patients and workers exposed to asbestos (Thörnqvist, 2005, p. 282). An alarm came towards the middle of the 1970s of cases of an unusual form of cancer, mesoteliom among workers in AB Bofors-Nohab in Trollhättan, that had been exposed to asbestos. The mentioned alarms led to sharpened regulations that were introduced in 1975 (Thörnqvist, 2005, p. 282). Asbestos was totally prohibited in 1982. In this process innovations were introduced to either replace asbestos, or associated machinery or methods. While asbestos had not been banned, the Swedish National Board of Occupational Safety and Health (Arbetarskyddsstyrelsen) prohibited the use of high speed machinery due the amount of asbestos emissions from 1977. AB Eternitrör had therefore (in 1976) developed a mechanical method for cutting and turning of asbestos pipes that was claimed to substantially reduce dusting (*Ny Teknik* 1976:30, p. 26). Some innovations dealt with problems emerging in the removing and replacement of asbestos. The process of dealing with and removing asbestos was regulated from January 1979, by regulations from the national board of occupational safety and health (Arbetarskyddsstyrelsen) in 1979 and therefore a need emerged to develop new methods. A special system with equipment was developed during two years by a working group involving the construction workers, the trade inspection (Yrkesinspektionen), the National Board of Occupational Safety and Health and three companies Dustcontrol AB, Slipnaxos and Pelles skrot AB to solve the problems (*Verkstäderna* 1979:6, p. 18).

Other types of dust were also given attention by public institutions and industry during the 1970s. The Swedish National Board of Occupational Safety and Health prepared guidelines for hygienic exposure limits (thresholds) for allowable amounts of dust. Dustcontrol AB had since the firm start in 1972 tried to solve problems with the hazardous dust that was generated in many industrial operations, including grinding, drilling, gouging and welding operations. This development (supported by STU) resulted in a local exhaust ventilation system launched in 1976 (*Automation* 1976:7, pp. 44-46; *Ny Teknik* 1976:34, p. 10; *Verkstäderna* 1976:15, p. 89).

4.4.2.3 Induced innovation

The final category, labelled 'induced' innovations are those innovations that were aimed to solve economic problems, e.g. hindering the rational or profitable production of goods. The label 'induced' is taken to mean that they are the response to changes in economic conditions, whether factor prices, profitability or technical obstacles to the rational production, transportation or use of goods. While having in common that they respond to a set of identified economic problems, these innovations are less straightforward to summarize. Induced innovations have frequently pertained to idiosyncratic problems of firms or technical problems identified in certain industries. Furthermore, the articles only seldom make a clear distinction between labor saving and capital saving innovations possible and it is often the case that several different types of economic problems are cited at once.

During the 1970s several industries came under a strong negative transformation pressure. In order to describe the development of induced innovations I will use the forestry industry as an example. The forestry industry emerges in the SWINNO database as one of the most prominent examples of how negative transformation pressure, originated in a set of closely interrelated social, technical and economic problems, has spurred innovation activity. In 1974 an acute shortage of wood emerged as a result of that the deforestation level had reached the maximum level allowed by Swedish legislation Josefsson (1985, p. 241). Several factors contributed to the development of innovations aimed to overcome difficulties hindering the rational felling of trees and/or the mechanization of other forestry activities. An article in *Sågverken* (1977:10, pp. 853-872) described several innovation projects (e.g. ground preparation machines) aimed to mechanize forest cultivation, and the major factors behind this development. Forest cultivation was described as being on the threshold of mechanization. The main driving force was the need of forest regeneration to reassure the supply of raw material for the expanding pulp, paper and wood processing industry. This development was also driven by the high labor costs relative to machinery. Unprofitability was an important problem in many forestry activities. Moreover, being a seasonal activity, there was a felt problem in forest cultivation with acquiring temporary labor. A far gone urbanization process and an overall reduced labor force in other parts of the forestry contributed to the shortage of labour (Ibid.). One might add that the forest workers strike could have contributed to the labor saving bias in the forestry industry. It was one of the largest strikes in the post-war era. It lasted from March to June 1975 and involved 15 000 forest workers. Like the miners strike in 1969, workers demanded an abolishment of the piece wages (Nohrstedt, 1977).

The SWINNO database contains several attempts made to introduce new methods, machinery and tools to achieve a mechanization of forestry activities for one or several of the reasons described. Whole tree deforestation was considered a more efficient way to make use of the trees and make felling profitable. Many of the innovations were also attempting to eliminate technical obstacles to mechanization. For instance, one of the reasons why the mechanization of tree felling was lagging behind was the lack of felling tools that could compete with manual labour. Such a tool was therefore developed by Östbergs Fabriks AB (ÖSA) and the Swedish Forestry Research Institute (*Sågverken* 1977:2, pp. 97-101, 125).

The shortage of wood also affected sectors downstream. Both the wood processing industries and the pulp and paper industries were affected, while simultaneously struggling with higher energy costs and a felt pressure to adopt or develop environmentally friendly production methods. Thus one may observe machinery, electronic and other innovations that attempted to economize on the raw materials. Some firms launched methods and machinery to produce wood and wood products out of waste materials, for instance, a machinery to produce chip wood by stumps and waste wood was launched in 1975 by Piteå Maskinindustri AB (*Sågverken* 1975-11, p. 839). Another method to produce planks and boards from fiber material from garbage was developed. According to the responsible for the development "Now ... sawmill owners do not need to complain about the shortage of raw materials any longer" (*Sågverken* 1977:10, p. 905).

The case of the forestry industry and the innovations responding to the complex set of factors involving unprofitability, rising energy costs, strikes and a felt need to automate production could be extended to other industries, such as the paper and pulp industry and the mining industry. Other industries, also hit by a complex set of factors associated with a negative transformation pressure were not equally responsive in terms of product innovations (e.g. the steel industry that may have directed response towards process innovations instead, see chapter 5).

4.4.3 Crisis and boom of the 1990s. Software, telecommunication innovations and biotech

Whereas the innovation activity during and following the structural crisis has been shown to be ample, the crisis of the 1990s was not marked by surges in the rate of innovation. Despite a strongly felt crisis, that in terms of GDP decreases surpassed the depression of the 1930s (Edvinsson, 2005), there is no evidence for innovations driven by creative response to economic adversity in terms of the count of innovations commercialized. The exceptions are machinery for the production of pulp and paper (SNI 29550) and textile, wearing apparel and leather innovations (SNI 170-190).

Instead, the pattern of innovation activity during the period 1990-2007 can be described as predominantly driven by a positive transformation pressure. It has previously been shown that in a group of industries there was a surge of innovation after the crisis of the 1990s (see Figures 4.4 and 4.7). Descriptive statistics for this group of industries was summarized in Table 4.4. This group consisted *inter alia* of software and computer related services (SNI 720), telecommunication equipment (SNI 322 and 321), medical and surgical equipment (SNI 331), instruments and appliances for measuring (SNI 332), parts for motor vehicles (SNI 343) as well as pharmaceuticals (SNI 244). This group thus corresponds well to what has been called the ICT sector and the biomedical sector. The share of these innovations increased throughout the period from 10.2% to 50.0% of the total count of product innovations between 1970 and 2007.

What were the forces behind the increase in innovation activity after the 1990s? Behind the surge in innovation activity after the crisis of the 1990s lay a continued diffusion of micro-electronics and a vigorous development of telecommunication and Internet technologies. During the 1980s and 1990s the technological and business opportunities created by the introduction of digital systems, mobile telephony services and Internet were becoming ample. The falling prices of electronic components made possible a wider diffusion of electronic equipment, now reaching final consumers at a broader scale. Telecommunication equipment and software aimed for consumers thus came to the fore.

4.4.3.1 Mobile telecommunications and consumer electronics

The development of the telecommunications industry has been described in terms of two phases (Fransman, 2001, 2002; Karlsson, 1998). The development of telecommunication equipment in Sweden was since the time of the first world war dependent on two actors: L M Ericsson and network operator Televerket (before 1953 named Telegrafverket). Televerket became a *de facto* monopoly in 1918.The market structure changed during the 1980s. Deregulations began on an international scale in the mid-1980s in the US, Japan and the UK (Fransman, 2001, 2002). Sweden was no exception. In the view of Fransman (2001, 2002) the new opportunities brought about by the micro-electronics revolution spurred the entry of new actors with an interest to deregulate telecom markets. Together with users such actors drove the Swedish liberalization process (Karlsson, 1998, pp. 219-220). Deregulations began already in 1971 with the introduction of MTD (Mobile Telephone System D). Competitors were now allowed in the production of mobile telephones.[9] Apart from the case of mobile telephones, Televerkets monopoly was however not more substantially deregulated until the 1980s. The monopoly was completely abolished with the Telecommunications Act of 1993. The deregulation of telecommunication equipment certainly was the source of new firms and innovations in the fields of mobile telephone equipment and networks.

Naturally, innovation activity was until the deregulation of 1993 heavily centered on Televerket or Ericsson. Key innovations in mobile telephony were developed by these two actors during this period. The AXE switch, de-

[9] Some examples of firms entering the market at this point exist in the SWINNO database, e.g. Doro Telefoni and Spectronics, see chapter 7.

veloped by Televerket and Ericsson's jointly owned subsidiary Ellemtel was one of Ericsson's most important innovations throughout its history. Ericsson's previous switching systems, such as the AKE-system, developed during the 1960s had not been a success. The then extant SPC (Stored Program Control) stations were unsatisfactory and were rapidly becoming obsolete as the technology of electronic circuits developed enabling lower memory costs at a higher rate. There was a need therefore to develop a new cost efficient SPC system and search was initiated for a new type of system, that became AXE (Meurling et al., 1997; Meurling & Jeans, 2000). AXE was launched in 1976. Another major innovation was the Nordic Mobile Telephone system (NMT) that began development in 1970. The seeds of NMT can be traced back to an internal investigation by Televerket in 1967, recommending the development of a Nordic system for mobile telephony (Mölleryd, 1999).[10] NMT was launched in Sweden in October 1981.

Having overcome quality problems in the development of car and portable telephones, the first portable telephone designed for NMT was developed and launched by Ericsson in 1989 (*Ny Teknik* 1989:38, p. 49; Meurling & Jeans 2000). Spectronic launched a competing mobile telephone, the world's smallest (*Ny Teknik* 1989:40, p. 38; 1990:42, p. 6; 1990:51-52, p. 14).

Ericsson specialized in mobile telephones and became a world-leading actor towards the end of the 1990s. According to McKelvey et al. (1997) and Meurling & Jeans (2000), Ericsson became focused on mobile telephones only after failing its strategy of integrating telecommunation and computer technologies to create "the paperless office".

The deregulations of 1993 was followed by a wave of product development and entrant firms in the field of telecommunications. The count of mobile telephone and consumer electronics innovations increased after the crisis of the 1990s and culminated in 1999-2000. Though many firms were small entrants, Ericsson accounted for a large part of these innovations. Ericsson for instance developed the first wap phone (2000), the first Bluetooth product (though the Bluetooth technology was developed by a consortium of mobile telephony actors) and the first mobile telephone supporting both Bluetooth and MMS (Multimedia Messaging Service). Other consumer electronics innovations were developed by entrant firms. Array Printers was started in 1987 to develop and commercialize a printing technology, Toner Jet, invented by the founder Ove Larsson. Array Printers

[10]MTD was developed as an interim system to NMT as NMT was not expected to be ready until the late 1970s (Mölleryd, 1999, p. 88).

launched two innovations (a new fax machine 1994 and four colour printer 1995). Axis Communications was a highly successful firm, started in 1984 to develop and sell printer interfaces. In 1995 Axis launched the world's first centralized IP camera "Neteye" (*Elektroniktidningen* 1996:15, p. 8; *Ny Teknik* 1996:38, p. 18; for an in-depth description of Axis, see chapter 7). Another entrant firm developing consumer electronics was Anoto, started in 1996 as C Technologies by Christer Fåhraéus. Anoto's core innovations were C Pen, a pen that transmits text to mobile phones via Bluetooth (*Ny Teknik* 2000:16, p. 28; 2000:46, p. 35; 2003:12 Part 2, p. 1; *Elektroniktidningen* 2002:7, p. 15; *Telekom Idag* 2001:8, p. 15; *Automation* 2002:5, pp. 24-26), and an image processing circuit invented by Fåhraéus that lay at the core of the camera technology of the scanning pen (*Ny Teknik* 2002:15 Part 2, pp. 10-1; 2002:43 Part 2, p. 15; 2002:25-33 Part 2, pp. 8-9; 2003:5 Part 2, p. 10).

4.4.3.2 The deployment of Internet technology: transmission systems and network components

The first Swedish network was connected to the Internet in 1984. Internet however did not became publicly available in Sweden until 1994, when Algonet connected Internet with the Swedish telephone network and provided Internet access. The ensuing deployment of Internet and telecommunication networks has apart from network standards required investment and innovation in data communication equipment, transmission systems and network components.

The co-evolution of components and network technologies and standards is well-known. Imbalances and technological bottlenecks, have been driving development of these innovations to a considerable extent (see Chapter 6 for a more elaborate treatment). These types of innovations have played a large role in the the deployment of Internet technology. The development of ADSL technology (Asymmetric Digital Subscriber Line) was commenced internationally to adress a capacity bottleneck (Fransman, 2001, pp. 125-126). When Telia was the first in the world to transmit high resolution TV images using the later transmission technology VDSL (Very high speed Digital Subscriber Line) it was noted that modems and network components were necessary for a commercially functioning technology (*Ny Teknik* 1997:15, p. 4). In 1999 Telia Research could launch a series of chips adapted for VDSL, developed together with the French chip manufacturer ST Microelectronics (*Ny Teknik* 1999:45, p. 11). Other transmission systems were developed to overcome capacity bottlenecks in the data transmission for personal users (e.g. Ericsson's Cobra World Wide Web (*Ny Teknik* 1996:24, p. 4).

Ericsson developed innovations in several of these fields. Innovations spanned not only mobile telephones, but data communication equipment (e.g. modems), network switches, optic fibers, installation tools for fiber cables, mobile positioning systems and radio systems. Innovations were however to a great extent developed by entrant firms, frequently based on spin-off projects from Ericsson or research institutes in the field (e.g. Acreo or Industriellt Mikroelektroniskt centrum). Examples contained in the SWINNO database are:

- firms launching different kinds of transmission systems (Lumentis, Transmode, Net Insight),
- components (Albax Systems, Altitun and its successor Syntune, Comlase, Optotronic, Optillion, Proximion, Silex, Phoxtal Communications)
- and network switches (Dynarc, Netcore and its successor Switchcore, Xelerated).

Almost without exception the innovations launched by these firms were directed towards solving critical problems in the expansion of networks. For instance, Netcore (later renamed Switchcore) launched a circuit that could handle both ATM and IP technology. The technology came from a research project in which Ericsson Components, Saab Dynamics, the Royal Institute of Technology and the Universities of Linköping and Lund participated (*Elektroniktidningen* 1997:19, p 4 *Ny Teknik* 1998:25-32, pp. 16-17). The circuit was customized for IP switches and routers for the Gigabit Ethernet standard. With increased traffic, the data switch was a bottleneck, but with Netcore's circuit it became possible to build faster and cheaper switches. The innovations of Dynarc and its sister company NetInsight, stemmed from the research group at the Royal Institute of Technology that since the 1990 developed DTM (Dynamic Sychronous Transfer Mode), a network protocol enabling high speed data switching and increased capacity in IP networks. Net Insight launched a network technology able to provide speeds of several terabits per second. (*Ny Teknik* 1998:25-32, pp. 16-17) Dynarc developed a PBX for IP networks based on DTM commercialized in 1998 (*Telekom idag* 1998:8, p. 11; *Ny Teknik* 1998:25/32, pp. 16-17).[11]

[11] See also section 6.4.1.3 in chaptter 6 for a discussion of how these innovations were indicative of an expanding development block.

Some firms were defying the recession of 2000-2002. Phoxtal Communication developed a wave length switch for optical fiber networks to solve a technical problem in wave length multiplexing (the enabling of addition and switching between wave lengths to different users without having to replace physical components (*Ny Teknik* 2004-14, p. 10). The origins of Lumentis was that former Ericsson engineers had observed the traffic problems and the need to connect remote networks to metropolitan area networks so that operators effectively can reach their end customers. Thus, in 2000 they started development of a DWDM (Dense Wave Division Multiplexing) solution for metro networks that do not require optical amplifiers (*Elektroniktidningen* 2001:15 p. 6; *Ny Teknik* 2002:16 Part 2, p. 10; 2002:43, pp. 8-9).

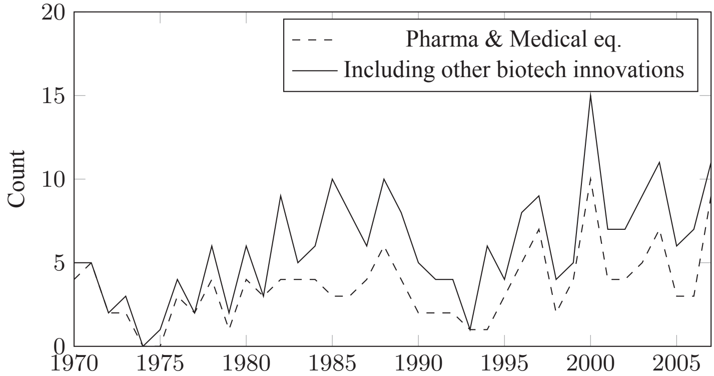
A second source of innovation has been various security problems that early on followed the introduction of industry and personal computers and data communication systems. Already in the 1980s there were Swedish innovations aimed to prevent database hacking, or computer thefts.[12] As more people began using the Internet, and as more transactions were carried out over the Internet several firms also emerged in the late 1990s that were attempting to eliminate obstacles to secure transaction online, e.g. Surfbuy and Buyonnet. Other firms developed systems for secure identification online or in mobile phones. Fingerprint Cards and Prosection are firms notable for developing biometric systems (e.g. Fingerprint Cards' fingerprint recognition system for mobile telephones).

4.4.3.3 Medical innovations and biotechnology

Pharmaceutical innovations and medical equipment are two product groups, like telecommunication and software innovations have been characteried by a steady increase during the period. Swedish firms and inventors have developed several path-breaking medical innovations. Rune Elmqvist developed the first pacemaker in 1958, launched by Elema-Schönander AB. An artificial kidney was invented in 1965 by Nils Alwall and Lennart Östergren, and was the reason for the start of medical firm Gambro AB (Wallmark & McQueen 1991; *Kemisk Tidskrift*; 1970:4, p. 34; *Plastforum* 1970:3, p.

[12]For instance, Concentus, an electronics company formed in Norrbotten, developed a Swedish modem with filter for hackers, launched in 1985 (*Ny Teknik* 1985:47, p. 47). Nordnet and Alfanet launched two data security systems in 1988 aimed to protect against hacking (*Ny Teknik* 1988:9, p. 28).

Figure 4.10: Count of pharmaceutical, medical equipment and other innovations exploiting biotechnology, 1970-2007.



50).[13] Leksell Gamma Knife, for treatment of vascular malformations and brain tumors was developed by the medical doctor Lars Leksell in the 1950s. The firm Elekta was founded in 1972 to commercialize the invention which was launched in 1984 for generic clinical use (*Verkstäderna* 1988:11 p. 68; *Ny Teknik* 2001:5, Part 3, p. 8).[14] Pharmaceutical companies, such as Astra (AstraZeneca) have launched several new-to-the-world innovations. Examples are Xylocain (developed by Astra, launched 1948), the beta-blockers Aptin (developed by Hässle, launched in 1967), Bricanyl (developed by Draco, launched in 1970) and Seloken (developed at Hässle, launched in 1975).

The advances made in pharmaceuticals and medical equipment became during the period studied closely connected to what has been called the biotechnology sector. The count of biotechnology innovations, medical innovations and pharmaceutical increased during the 1980s and the 1990s in particular (see Figure 4.10). The biotech industry was initially tied to the Swedish pharmaceutical companies, such as Astra, Pharmacia, Kabi, Ferring, Leo and in part LKB-Produkter (Stankiewicz, 1997; Backlund, Markusson, et al., 2000).[15] The first application of biotechnology came

[13] This was a modified version of the kidney dialysis machine invented by Dr. Willem Kolff in 1943.

[14] Leksell had in 1950 discovered that a thin, highly concentrated proton beam could remove tissue in the brain without risk of bleeding of infection.

[15] Leo and LKB-Produkter were later bought by Pharmacia. Kabi was merged with Pharmacia in 1990, and became Kabi Pharmacia. Ferring became internationalized and did not

in the 1980s. The first firm that applied biotechnology in Sweden was Kabi, later incorporated into Pharmacia. Kabi was developing Hybrid-DNA manufactured insulin (launched in 1983) and the world's first biosynthetic growth hormones, e.g. Genotropin, launched in 1987 (*Ny Teknik* 1983:46 p. 3; *Kemisk Tidskrift* 1987:6, pp. 20-21; 1995:9, p. 16). Complementarities have emerged between the development of medical and electronic equipment and the development of pharmaceuticals and diagnostics. In the 1980s several separation instruments and processes were developed, aided by microelectronics. Exploiting microprocessors, LKB-Produkter, developed several analysis systems and separation equipments that were aimed for faster analysis and separation of biological substances (*Kemisk Tidskrift* 1982:7, pp. 33-34; 1986:13, p. 53; 1985:5, p. 47). The innovation activity in biosensors is also case in point. Pharmacia developed the world's first biosensor, launched in 1989. At the time biosensors were described as filling a technological gap in medical diagnostics, namely the lack of simple, fast and cheap methods to measure specific chemical substances (*Ny Teknik* 1990:3 p. 5; *Kemisk Tidskrift* 1985:7, pp. 6-10). Out of Pharmacia's biosensor activity (the division Pharmacia Biosensor AB) grew Biacore AB. Other firms followed during the 1990s developing biosensors, e.g. Bofors Applied Technologies (spun off to Biosensor Applications), Bioett AB, Biochromix, Attana and Midorion. Biosensors had towards the end of the period found commercial applications outside laboratories, e.g. to detect narcotics in airports.

PyroSequencing and Robolux are other examples of entrant firms developing instruments and methods for biotechnical applications. Pyrosequencing's system for DNA sequencing was based on a new method developed at the Royal Institute of Technology (*Kemivärlden* 1999:6, p. 15; 2002:2, p. 16; *Ny Teknik* 1999:37, p. 9; 2000:39, p. 20). Robolux was founded in 1993 by Ingvar Backlund (then working as a technology consultant at Pharmacia Biotech). He had figured out a new way to construct valves for the demanding environments found in biotechnology and modern pharmaceutical manufacturing (*Kemivärlden* 2001:4, pp. 49-50, *Automation* 1995:5, p. 13).

Like ICT innovations, biotechnology innovations cut through product classifications. By no means are these limited to pharmaceuticals. By contrast, innovations exploiting biotechnology can also be found in the agriculture, foodstuff, energy and forestry industries. Biotechnology has also been applied in the foodstuff industry primarily in fermentation processes and

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conduct R&D activity in Sweden (Backlund, Markusson, et al., 2000, pp. 12-16).

in the development of functional food. Probi AB and Lipid Technologies were active during the 1990s in launching functional food. Notably, Probi AB was started in 1991 to exploit and develop its patented bacterium *Lactobacillus plantarum* 299V. This led to a series of products, among which ProViva is notable, launched by Skånemejerier.[16] LipidTeknik began in the early 1990s to develop lipids for food products (e.g. Skånemejerier's "Olibra") enabling prolonged satiety (*Livsmedelsteknik* 1998:1-2, p. 34). Arla's soured milk "Onaka", launched in 1990, was the result of a collaboration with a Japanese firm, Morinaga, involving the bacterium *bifidus*. Biotechnical innovations have to some extent also been developed for use in agriculture. For instance, BioAgri developed a biological pesticide (called Ceromon) for replacement of some of the toxic chemicals that were used in etching of grain (*Ny Teknik* 2000:38, p. 11; 2002:37, p. 6).

4.4.3.4 Environmental innovations in the 1990s and 2000s

While the bulk of environmental problems were concentrated to the first half of the period, it is worthwhile to stress that the latter half of the period saw a number of innovations aimed to solve environmental problems, or to solve obstacles to the introduction of new environmentally friendly technologies. Some of these innovations are discussed elsewhere in this thesis, but a brief overview is given here.

Many of these innovations were developed in the fields of renewable material and energy technology and emission control technology. Climatewell, Arontis, Midsummer and Sunstrip were firms developing innovations to solve obstacles to the wider use of solar energy (see also section 6.4.2.3). Innovations for the production of biofuel were numerous. Chemrec, and Lignoboost were examples of firms developing techniques to produce biofuel from black liquor, a residue from pulp production (see also section 6.4.2.3). Termiska Processer i Studsvik (TPS) developed a gasification

[16]The development of ProViva is described in one of the articles. "It all began in the mid 80's at the surgical clinic in Lund. The doctors needed help patients who would undergo major surgery. These are done in the fasting state while the patient receives doses of antibiotics . Normal intestinal bacteria are eliminated and more aggressive take over. At worst, these knock out vital rogan in the body. The doctors turned to Kåre Larsson, who was then a professor in the Department of Food Technology at Lund University , and was advised to tube feed patients with oats. Professor of Microbiology, Nils Molin, helped to get the right consistency [...] by the bacterium Lactobacillus plantarum 299 v. Kaj Vareman at Ideon research village was connected and Probi AB was formed. The product was called ProViva and was introduced in 1994 by Skånemejerier" (*Livsmedelsteknik* 2000:6-7, p. 8; translation by the author).

technology for biofuels (*Ny Teknik* 1995:36, pp. 24-25; *Ny Teknik* 1998:24, p. 10). Ageratec developed a small scale facility for the production of biofuel from oil or fats (*Ny Teknik* 2006:45, pp. 26-7). The period also saw several innovations in emission control technology, or automotive vehicles or motors exploiting emission control technology, as well as hybrid electric vehicles (see sections 6.4.3.1 and 6.4.3.3). Several innovations were launched by the large automotive and truck manufacturers (Volvo, Saab and Scania). Others were developed by new firms. Emission Technology Group developed a system for exhaust emission control (*Transport idag* 2004:11, p. 7).

Other clean technology innovations were renewable materials or products aimed to replace the use of hazardous chemicals. These were often driven by new environmental regulations PP Polymer developed several such innovations, among those an environmentally friendly glue (*Ny Teknik* 1996:34, p. 22) and flame retardant aimed to replace the use of hazardous halogens (*Kemivärlden* 2004:3, p. 5; *Kemivärlden Biotech med Kemisk Tidskrift* 2006:6, p. 8).

4.5 Conclusions

The empirical analysis of this chapter points to two surges of innovation activity as measured by the counts of innovations commercialized. It was shown in this chapter that these two surges can be decomposed, and statistically explained, by innovations driven by technological opportunities and technological bottlenecks, and innovations driven by techno-economic and environmental, organizational and economic problems.

The first surge in innovation activity took place during the period 1975-1984, i.e. during and following the structural crisis of the 1970s. This surge resulted both from the diffusion of ICT technology and negative transformation pressure. Negative factors appear to have been a more important factor among those innovations launched early in the crisis, i.e. 1975-1979, whereas ICT innovations peaked in 1983. The second surge took place during the 1990s, predominantly carried by telecommunication and software innovations and the biomedical sectors (SNI 244 and SNI 331). This surge resulted from the exploitation of technological opportunities, rather than stemming from negative transformation pressure.

In the final part of the chapter, the main factors behind the surges of innovations were described by way of cases from the SWINNO database. The analysis highlighted groups of innovation that were driven by similar technologies or problem complexes. The groups of innovation driven by negative transformation pressure during the structural crisis highlighted the deep character of the crisis. The crisis was not only an economic crisis, but also an energy, cost, and in some respects a social and institutional crisis. A result of this chapter is that these aspects of the structural crisis, rising energy costs, work environmental problems and a felt negative transformation pressure, were blatantly visible in creative response. The aspects of the structural crisis affected innovation activity in full force. Based on the qualitative description one may reject a simple interpretation of creative response to crisis as rooted in one factor only (e.g. factor prices, oil prices). The forestry industry is a case in point. Rather, social, institutional, economic and technological forces were simultaneously at work, feeding in to the patterns of creative response.

The results regarding the pattern of ICT innovations corroborate the analysis of Schön (1994, 1998, 2006, 2010). ICT innovations were diffused during the early 1980s and on a broader basis after the transformation crisis (1990-1994) in a pattern that is reminiscent of long swings of 15-25 years of duration. The first surge was more focused on industry applications, in a development block formed around factory automation. The second surge was carried by a development block formed around the investment projects of Internet technology, and home electronics. The deregulations of the telecommunications markets in 1993 spurred innovation and the entry of new firms.

These broader results do not appear to support a view of the launching of innovations as being either pro- or counter-cyclical over the course of a structural cycle. Rather, these results suggest that the pattern of innovations are to a large extent determined by positive and negative factors that transcend the short term business cycles.

5. Transformation pressure and industrial patterns of innovation

5.1 Introduction

The previous chapter has informed us of two periods of surges in the patterns of innovation in the Swedish manufacturing industry. These were concentrated to the crisis of the late 1970s and during the boom of the 1990s. Both positive transformation pressure, e.g. in the diffusion of micro-electronics, and negative transformation pressure, have been discussed as factors behind these surges. Chapter 4 has also shown the existence of three types of long term patterns in the count of innovations. One group of products displayed an increasing pattern over time. A second group was characterized by a long term decline, but with an increase during and following the structural crisis. A third group of products displayed a secular decline in the count of innovation. In keeping with the analytical purposes of this thesis, this chapter aims to *describe and explain differences in patterns of innovation across industries*. This analysis aims to contribute to the understanding of how long run patterns of innovation are connected with transformation pressure, and how such transformation pressures have historically generated creative response across industries. This chapter answers two questions

- What differences are there in patterns of innovation across industries?
- How has transformation pressure (e.g. technological opportunities, regulations, techno-economic problems or demand) shaped industrial patterns of innovation activity?

A vast literature has pointed to the existence of regularities in the industrial patterns of competition and innovation across industries and over time (Abernathy & Utterback, 1978; Abernathy & Clark, 1985; Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Utterback, 1994; Audretsch, 1995; Klepper, 1996; Malerba et al., 1999; Marsili, 2001; Malerba, 2002; see also Peltoniemi, 2011 for an overview). Empirical work on *technological regimes* suggests the existence of long-term industrial patterns of innovation as regards the number and size of firms, technological opportunities and knowledge base (see e.g. Breschi et al., 2000; Marsili, 2001; Malerba, 2002). As noted in chapter 2, thes analyses may be amended by employing a broader notion of driving forces. This chapter extends the analysis by linking such patterns of innovation to different types of transformation pressures, drawing on the Dahménian framework (Dahmén, 1950, 1991a). The discussion in chapter 2 resulted in a set of propositions about how transformation pressure may be related to the evolution of industries. Advancing industries, were argued to be likely to have a large number of innovations, enabled by the exploitation of technological opportunities. In advancing industries innovation activity is also expected to be motivated to resolve technological bottlenecks. In stagnating or receding industries, characterized by a negative transformation pressure, innovation activity is likely to be oriented towards finding niche markets, or towards solving economic problems, such as obstacles to the attainment of rational production or lower costs.

In order to describe and explain differences in innovation activity across industries and to analyse the role of positive and negative transformation pressure in industrial patterns of innovation, the chapter is organized in three parts. The first part introduces the research strategy to assess differences across industries in innovation and transformation pressure. The second part investigates the differences across industries and time as regards the origin of innovation, and the type of innovating firms. Differences across industries are examined and described in terms of long-term patterns of innovation, the size of innovating firms and sources of transformation pressure. Principal Components Analysis (PCA) is employed to examine the structure of correlations across industries between the types of transformation pressure, market structure and innovation performance over time. PCA gives a basic idea of the main differences between industries, and what industries were similar in terms of patterns of innovation and transformation pressure. The third part develops the previous statistical results to construct a categorization of industries that describes main patterns in how transformation pressure (technological opportunities, law changes, techno-economic problems, economic performance etc.) has shaped innovation activity in a selection of industries.

5.2 Approaching industrial patterns of innovation

5.2.1 Market structure and novelty across industries

In previous research on industrial patterns of innovation, a wide array of variables and concepts has been used to describe different types of patterns of innovation across industries. Of these, the market structure has traditionally been at center of Schumpeterian analysis. Two patterns are typically distinguished: a *creative widening* pattern, also called Mark I, where innovations are brought forth by innovators that have not innovated before and a *creative accumulation* pattern, also called Mark II, where innovations are brought forth by incumbent innovators.

In a seminal contribution, Pavitt (1984) proposed a taxonomy distinguishing between four types of patterns of innovation on the basis of the market structure, knowledge base and development trajectories of innovation activity. These observed patterns of innovation indicate how particular long-term patterns of innovation have arisen in the history of industrial capitalism. In *Science-based* sectors, e.g. chemical industries, product and process development is intrinsically linked to the emergence of scientific discoveries. Innovation is to a large extent opportunity driven and firms tend to be large. In *Scale-intensive* sectors, e.g. transport equipment, technological development is generally dealing with complex systems, benefiting economies of scale and large firm dominance. *Supplier dominated* industries, e.g. wood and simple metal products, are industries in which users are price sensitive and as a result cost-cutting process innovations come to dominate. *Specialized supplier* industries, producing intermediate and capital goods for most sectors, are characterized by small firm dominance and specialized knowledge processes. For instance the mechanical engineering industries belong here (Pavitt, 1984, p. 354; Dosi, 1988, pp. 1148-9).

In a similar vein, other authors have more recently developed the notion of technological regimes, based on the understanding of market structure and technological change as endogeneous. The notion on technological regimes (e.g. Malerba & Orsenigo, 1993; Breschi et al., 2000; Malerba,

2002) departs from the assumption that there are two determining factors of the intensity of innovation and the market structure: technological opportunities and appropriability conditions. In principle a creative destruction pattern can be explained by high technological opportunities and low appropriability conditions. Conversely, high appropriability conditions and cumulative conditions may explain the emergence of a structure where only a few actors innovate.

Inter-industry differences in the size of innovating firms and the character of innovation may also be understood dynamically. Taking a long term view, a vast literature has suggested a stylized pattern over time (Abernathy & Utterback, 1978; Abernathy & Clark, 1985; Abernathy & Utterback, 1978; Gort & Klepper, 1982; Anderson & Tushman, 1990; Utterback, 1994; Klepper, 1996). These viewpoints typically distinguish between a number of different phases of industry development (see section 2.3.2). The "embryonic" phase begins with the commercial introduction of a basic innovation. The "growth" or "fluid" phase is a phase of industrial emergence, where the entry of new firms and the development and introduction of a large number of product innovations are spurred by technological opportunities. During this phase innovation activity is exploratory and innovation may be radical from the firm or market point-of-view. During a third phase "maturity", products become more standardized and the number of competitors may stabilize or begin to decline. The focus of industrial development shifts from product innovation to cost-minimizing and rationalizations favoring process innovation among larger firms. During the "decline" phase there is an industry shake-out and market concentration. While product innovations decline or stagnate in absolute numbers, inter-firm competition or technological opportunities may incite product innovation among large incumbent firms.

These accounts thus suggest a temporal evolution and relationships between the number of innovations, the degree of novelty of innovations, the technological opportunities and the market structure. If these accounts are interpreted strictly, the market structure is assumed to thus vary from a Mark I pattern in embryonic stages to Mark II patterns of creative accumulation in stages of maturity or decline.

5.2.2 Transformation pressure in industrial development

The previous accounts ascribe importance to technological opportunities. However, in the point-of-view taken in this thesis there are other determinants of innovation which may help explain patterns of innovation over time and across industries. The briefly reviewed accounts of inter-industry patterns of innovation may be complemented with the notion of transformation pressure. Transformation pressure may broadly be understood as a strong incentive for firms to transform their economic activities. Such incentives may stem from a wide host of circumstances. This encompasses not only technological opportunities as suggested by the literature on technological regimes, but also negative factors.

Transformation pressure is multifaceted. There are many different sources of positive and negative transformation pressure, and there are therefore various ways to approach the issue of transformation pressure and innovation. Erixon (1991, pp. 259-261) and Erixon (1995) noted various components of negative transformation pressure: a) political pressure, b) foreign competition, c) domestic competition, and d) pressure stemming from the components of the gross product, i.e. pressure from product markets, raw material markets, labor and capital markets. One may accordingly generalize these components by distinguishing between institutional (or political), competitive and techno-economic sources of transformation pressure.

In the current analysis transformation pressure is approached in two ways. The long-run differences in transformation pressure are in principle possible to approach using quantitative analysis. The approach of Dahmén (1950), extended by Ljungberg (1990), using value added volume growth and change in prices was discussed in chapter 2 and Table 2.4. To recapture, relative value added volumes may distinguish between industries characterised by a long run positive or negative transformation pressure. The change in relative prices indicates whether transformation pressure stems from factors internal or external to the industry. Recent research (Svensson Henning, 2009) has used value added volume data to characterize the growth trajectories of Swedish industries. In the same spirit, the below analysis relates the innovation trajectories to the Dahménian taxonomy of relative value added volume growth to characterize the positive and negative transformation pressure across industries in the *longer run*.

It may be noticed here that other studies also have proposed measures of profitability as indicators of transformation pressure. Lindmark & Vikström (2002) suggested that declines in profitability might capture negative transformation pressure and that the inter-industry dispersion in profitability reflect both positive and negative transformation pressure. Erixon (1991, 2007) has emphasized falling profitability (as measured by the share of profits in value added) as an indicator of negative transformation pressure. The advantage of these measures is that they also take into account pressure stemming from labour costs, which according to induced innovation theories may spur process innovation. In principle, the best option would be to employ both value added volumes and profitability measures as indicators of transformation pressure. However, there are certain issues with aggregate profitability measures and statistics that impede a comparison across industries in this work. Moreover, one drawback to the use of profitability as an indicator of transformation pressure on the *industry* level is that negative transformation pressure may frequently be reflected in *rising* profitability when firms with below-average profitability exit or are wiped out.[1] Analysing value added avoids this problem since, in practice, firm deaths reduce value added volumes.

Second, the observed response to transformation pressure is analysed. Variables on innovations citing origin in technological opportunities and techno-economic problems are thus employed to assess to what extent innovation activity was the response to positive or negative transformation pressure. It is proposed that a measure of positive transformation pressure is a large number of innovations citing new technologies and new materials, and an origin in scientific advances as contributing factors to the development of the innovation (see below). Likewise, as argued in chapter 2, negative transformation pressure is expected to spur firms to initiate or intensify problemistic search among firms. Mainly, these problems may be related to irrational costs, work-environment issues and environmental problems. Thus an approach to negative transformation pressure is proposed to depart from a description of the types of problems that have contributed to the development of innovations.

5.3 Industrial patterns of innovation

This section first and foremost investigates how the long-term innovation performance is related to transformation pressure. Does transformation

[1] This was pointed out by Dahmén (1991b, pp. 128-129) as an example of the "fallacy of aggregative thinking".

pressure produce particular patterns of innovation? This section also investigates how firm size is related to the trend in innovation counts, the novelty of innovations and indicators of positive and negative transformation pressure.

5.3.1 Data and variables

The data used in this chapter stems primarily from the SWINNO database. The industry nomenclature used in this thesis has primarily been constructed to enable a meaningful differentiation of products that may be considered heterogeneous. All variables from the SWINNO database are therefore in principle possible to use for 61 manufacturing industries. While most of these industries encompass a larger number of innovations, there are a few industries in which the count of innovations is particularly low. Since this chapter, unlike the other empirical chapters, aims to explain and decompose industrial patterns of innovations it is sensible to exclude or aggregate industries which have a low count of innovations. Consequently, the nomenclature employed in this chapter differs somewhat from the rest of the thesis.[2] This chapter examines 48 manufacturing industries.

In sum, the current analysis distinguishes between four fundamental aspects of industrial patterns of innovation: the market structure, the degree of novelty of innovations, the long term patterns of volume growth and innovation, and origins of innovation in technological opportunities, or techno-economic problems. The variables are presented in Table 5.1. Summary statistics are presented in Table 5.2.

The first aspect of industrial patterns of innovation concerns the long term count and rate of growth of innovations and the long term patterns of value added. These patterns are assessed with the variables value added volume growth (ΔQ) and average annual rate of growth in the count of innovation $\Delta Inno$. In order to distinguish patterns of volume growth, value added volume growth rates have been calculated from consistent value added series on the lowest level possible. Due to the incompatibility of statistical nomenclatures SNI69 (in force until 1992) and SNI92 however aggrega-

[2] The industries excluded in this chapter were five industries with less than 15 innovations: publishing and printing (SNI 220), coke, petroleum and nuclear fuel (SNI 230), metallurgy machines (SNI 29510), weapons (SNI 296) and watches and clocks (SNI 335). Other industries were aggregated to the following four groups: SNI 313-316, SNI 29560, SNI 352-355 and manufacturing n.e.c. (SNI 360).

tions are unavoidable. The growth rates have been calculated for 35 industries. Due to this aggregation classifications based on the value added data must be interpreted as approximative as regards the sub-industries of the chemical industries (except pharmaceuticals, paints and varnishes) and parts of the machinery industries (except domestic appliances, agriculture and forestry machinery, general purpose machinery and mining and construction machinery).

The second concerns the patterns of the type of firms introducing innovations captured by the variables LARGE, SMALL and REC in Table 5.1. The first two are based on the number of employees of the innovating firms, employing two opposite poles of the size spectrum. Large firms are here defined as firms with 200 employees or more. Small firms are defined as firms with less than 50 employees. The last variable is constructed on the basis of the number of recurrent innovators: innovating firms which have launched at least two innovations. The share of recurrent innovating firms may be taken as a measure of the concentration of innovation activity.

The third aspect concerns the origins of innovation as the response to techno-economic opportunities or problems. Klevorick et al. (1995) discussed three sources of technological opportunities: scientific advances, technological advances in other industries and institutions and the industry's own technological advances. Two categories of technological opportunities are employed here: origin in new technologies or materials (NT) and origin in scientific advances or academic research (SCI). In addition to these, four main types of innovations are distinguished by the problem solved: technological bottlenecks (TE), i.e. economic obstacles to the introduction of new technologies, environmental problems (ENV), economic problems (EC) and problems related to the work-environment (ORG). The three latter can be understood as associated with a negative transformation pressure, whereas the first can be understood as associated with a positive transformation pressure. These variables were introduced in chapter 2 and 4 (see Table 2.5). In addition, innovations whose development was assigned by customers is measured (CUST).

The fourth aspect concerns the degree of novelty of innovations in terms of innovations that were entirely new (or radical) from the firm point-of-view (NEW) and the innovations that were new to the world market (WORLD).

Table 5.1: Central variables employed in this chapter

	Variable name	Description
Long term patterns	ΔQ	Average annual growth of value added volumes, 1970-2007
	Δ Inno	Rate of growth in the count of innovations[a]
Market structure	LARGE	Share of innovating firms with 200 employees or more
	SMALL	Share of innovating firms with less than 50 employees
	REC	Share of recurrent innovators (firms having launched more than one innovations)
Origin of innovation	TE	Share of innovations citing origin in the solution of a techno-economic obstacle to production or exploitation of new technology
	EC	Share of innovations citing origin in the solution of economic problems, e.g. production bottlenecks or irrational costs
	ENV	Share of innovations citing origin in the solution of a problem pertaining to negative externalities of the activities of firms
	ORG	Share of innovations citing origin in the solution of organizational problems
	NT	Share of innovations citing origin in new technology or material
	SCI	Share of innovations citing origin in scientific discovery or academic research
	CUST	Share of innovations assigned by customer
Degree of novelty	NEW	Share of innovations entirely new to the firm
	WORLD	Share of innovations new on the world market

[a] Calculated as θ in the Poisson regression $E(Y|t) = e^{\theta t}$.

Table 5.2: Descriptive statistics. Variables on novelty, market structure and transformation pressure, 48 manufacturing industries.

	Count of innovations	Average share	Max	Min
SMALL	1675	45.25%	68.23%	16.07%
REC	1843	49.78%	70.19%	20.59%
LARGE	1436	38.79%	78.57%	18.82%
TE	340	9.18%	38.71%	0%
EC	404	10.91%	43.1%	0%
ENV	366	9.89%	54.17%	0%
ORG	188	5.08%	25%	0%
NT	1302	35.17%	76.36%	0%
SCI	190	5.13%	27.06%	0%
CUST	334	9.02%	46.15%	0%
NEW[a]	1384	38.95%	76.6%	11.54%
WORLD	798	21.56%	54.9%	0%

[a] Shares are calculated by dividing by the number of observations of degree of novelty (3557) and not the total number of innovations. This applies to all calculations employing NEW below.

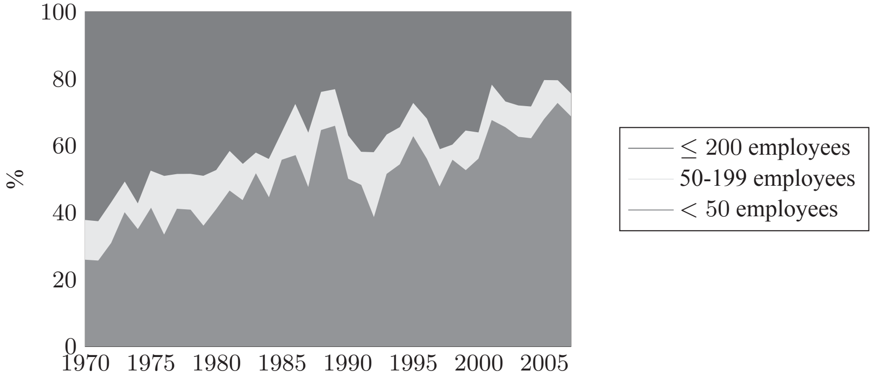
Note: Any discrepancy between this table and other chapters stems from the more limited sample used in this chapter (48 industries). The total count of innovations in the 48 industries is 3702.

5.3.2 Fundamental patterns of innovation

Before delving into industrial patterns of innovation it is useful to present some of the more basic results of the SWINNO database. Apart from the aggregate and industrial patterns of innovation over time (see Figure 1.1 and chapter 4), the SWINNO database reveals fundamental patterns of innovation as regards the the types of innovating firms. A fundamental result, shown in Figure 5.1 is the presence of a long term secular decline of large firms and an increase of importance of small firms. Thus there has been a shift in the types of innovating firms that appears to be a systematic feature of the industrial development during the period (see Sjöö, 2014 for a detailed discussion).

In order to give an overview of the fundamental inter-industry patterns of innovation patterns of firm size and transformation pressure is shown on the two-digit SNI level. These figures take a close look at the manufacturing industries studied here (SNI 15-36). Figure 5.2 shows the share of large firms (defined as firms with $\leq$ 200 employees) across two-digit manufacturing industries for the periods 1970-1989 and 1990-2007. The Figure

Figure 5.1: Distribution of innovations by number of employees of the innovating firm (%). Total database.



shows that innovation activity in some industries has been dominated by large firms throughout the period. This applies to the basic metals (SNI 27), automotive industry (SNI 34), other transport equipment (SNI 35), pulp and paper (SNI 21) and foodstuff (SNI 15). To a lesser extent this applies to the telecommunication industries (SNI 32) that were dominated by large firms (most notably Ericsson) but saw entry of new firms during the second half of the period. Innovation activity in industries such as wood products (SNI 20) and machinery (SNI 29) has been dominated by small firms throughout the period.

Figure 5.3 shows the distribution of innovations that have cited new technologies and materials as a contributing factor. Not surprisingly, the ICT sectors and chemicals have to a large extent been driven by opportunities. Plastic products (SNI 25), automotive vehicles (SNI 34) and pulp and paper (SNI 21) among others have had a rather low share of such innovations throughout the period.

Figure 5.4 shows the distribution of innovations responding to a negative transformation pressure, i.e. solving economic, environmental or organizational problems. ICT industries (SNI 30-33), foodstuff (SNI 15), other transport equipment (SNI 35) and basic metals (SNI 27) stand out as having had consistently low shares of innovations citing negative transformation pressure. At the other side of the spectrum, we find textiles (SNI 17-19), pulp and paper (SNI 21), wood (SNI 20) and machinery equipment (SNI 29).

Some industries stand out in general in terms of firm size, or the main

Figure 5.2: Share of innovations developed by large firms ($\leq$ 200 employees) across two-digit manufacturing industries (SNI 15-36), 1970-1989 and 1990-2007.

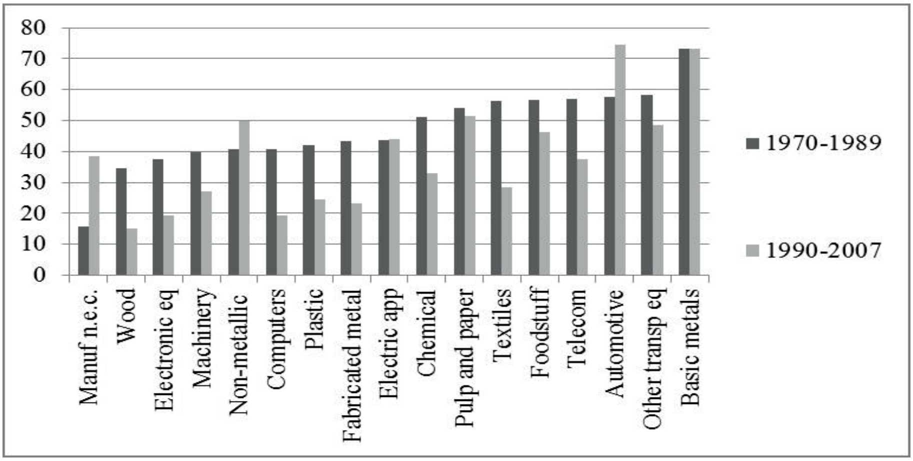


Figure 5.3: Share of innovations citing origin in new technology or material, across two-digit manufacturing industries, 1970-1989 and 1990-2007.

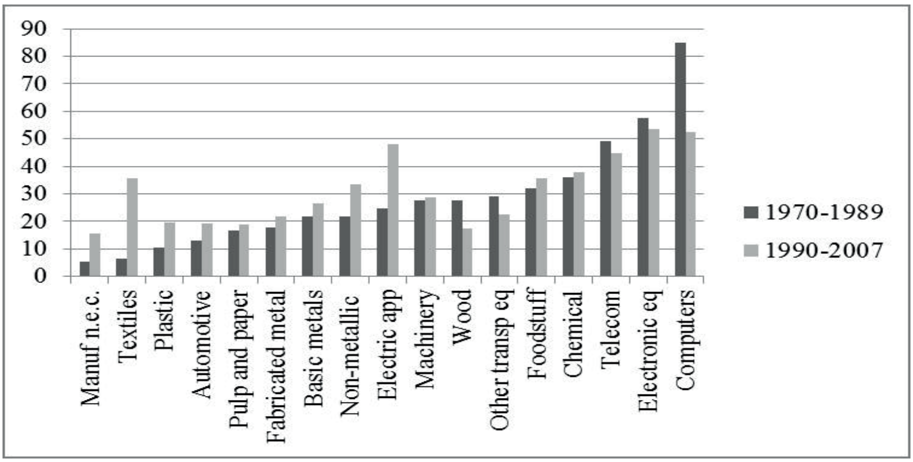
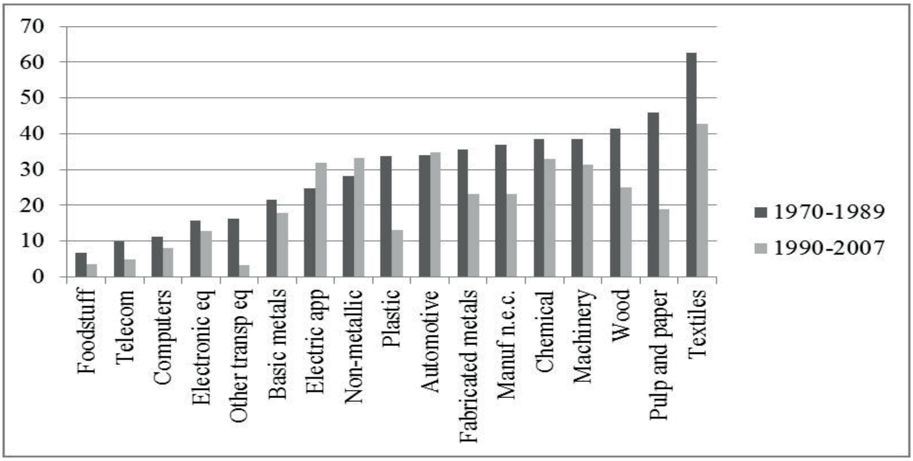


Figure 5.4: Share of innovations citing origin in negative transformation pressure, across two-digit manufacturing industries, 1970-1989 and 1990-2007.



source of transformation pressure. However, from Figures 5.2-5.4 there is no apparent pattern of co-variation between firm size and transformation pressure. Rather, among industries in which innovations have largely cited origin in new technologies or materials, some industries have had large shares of innovations developed by large firms (e.g. telecommunications and chemicals), others not.

To further examine the differences across industries and the relationship between firm size, transformation pressure and long-term patterns of innovation it is suitable to turn to a more statistical analysis.

5.3.3 Principal components of industrial innovation activity

The analysis proceeds from a holistic point-of-view employing the correlation matrix of variables and principal components analysis that enables us to discern the main components of the variation in market structure, novelty, transformation pressure and long-term innovation performance across industries. In Table 5.3 the correlations of the key variables are presented for the period 1970-2007. A first observation is that there are strong positive correlations between the variables associated with scientific origin, technological opportunities, volume growth and increase in innovation counts. These variables are also negatively correlated with the variables associated with problem-solving. From these basic observations one may draw two conclusions. First, there is a generally positive association between the long-run pattern of innovation and the direction of transformation pressure. Second, positive transformation pressure and negative transformation pressure, as measured here, appear to be two opposites on a spectrum. In industries in which innovations are the response to opportunities or technological bottlenecks, innovation activity is typically not simultaneously driven by a negative transformation pressure. Furthermore, one may observe that there is no systematic connection between volume growth or the rate of growth in innovation counts on the one hand and the variables associated with the type of innovating firms.

The complex structure of the correlations between variables may be further analysed by distinguishing the main components of inter-industry variations. Principal components analysis (PCA) is a common tool in exploring the structure of correlations between variables in a dataset when the variables are interrelated in complex ways. It has therefore been used extensively in the literature on technological regimes and inter-industry patterns of innovation (see e.g. Marsili, 2001; Marsili & Verspagen, 2002; Palmberg, 2004). Given a set of variables, the method finds a smaller set of uncorrelated (orthogonal) vectors, so-called principal components. The results are ordered, such that the first principal component captures the highest variance. Given a data matrix **X** of variables i and observations j, the principal components **Y** are calculated as a linear transformation of the original data set, with the objective to maximize the variance. The first principal component is calculated as

$$Y_1 = a_{11}X_{1j} + a_{12}X_{2j} + ...a_{1n}X_{1n} \tag{5.1}$$

such that the variance is maximized. The whole matrix can be expressed in succinct matrix notation as

$$\mathbf{Y} = \mathbf{A}^T\mathbf{X} \tag{5.2}$$

The coefficients a of matrix **A** are the variable loadings, and the values of **Y** are the component scores.[3]

The results are analyzed in terms of the component scores and factor

[3]The above applies in general. In the simplest case when the data matrix is de-meaned, the problem of finding the factor loadings is equivalent to finding the eigenvectors of the covariance matrix. In data sets with non-zero means it is sensible to use a correlation approach, in which the factor loadings are equal to the eigenvectors of the correlation matrix. The latter approach is carried out here.

loadings of each principal component. The component scores are the values of the principal component. A high component score of an industry indicates that the industry is positively related to the principal component. Thus it is possible to analyse similarities and differences across industries in terms of the principal components. The factor loadings of a principal component express the relation between the principal component and the original variables. The loadings can be used to interpret what goes into the principal component. A positive or negative loading of a variable may be said to indicate a positive or negative correlation between the variable and the principal component.

The results of the PCA focus our attention to three main components. The first three principal components account together for 60.4% of the variance and summarize the main differences in patterns of innovation between industries. The loadings are presented in table 5.4 and the loadings for the two first principal components are shown in figure 5.5. The first component separates industries with high rates of growth in innovation and volumes, high technological opportunities and high shares of new-to-the-firm innovations (TE, ΔQ, SCI, NT and NEW) from industries with low rates of growth in innovation and volumes, and high shares of innovations aimed to solve economic problems involving irrational costs and production bottlenecks (EC). This is fully consistent with the view that positive and negative factors are opposite points on a spectrum and reflect positive and negative patterns of innovations and volumes. The first principal component has accordingly been labelled *transformation pressure*. A positive (or negative) value suggests a positive (or negative) transformation pressure. The second principal component distinguishes industries dominated by large firms and high concentration from industries dominated by small firms and low concentration. This principal component has accordingly been labelled *market structure*. A positive (or negative) value suggests a large (or small) firm dominance. The third component separates out industries focused on the solution of environmental problems (ENV). It also separates out customer-oriented industries, such as shipbuilding (SNI 351) and weapons and ammunition (SNI 296).

The factor loadings and factor scores for the two first principal components are illustrated in Figures 5.5 and 5.6. The score plot shows, in accordance with the analysis elsewhere in this thesis, that ICT industries and biomedical industries were on the positive side of transformation pressure. On the other hand, in the bulk of machinery industries, facing declining volumes, problem-solving activity was directed towards the solution of production bottlenecks and irrational costs.

The two principal components suggest three main groups of industries. The results bear important resemblances to the Pavitt taxonomy. A first group consists of industries characterized by a dominance of new-to-the-firm innovations, technological opportunities and scientific discovery. This category may be compared to Pavitt's science-based industries. Among these some have a Mark II pattern of innovating firms, in particular pharmaceuticals (SNI 244), electric motors (SNI 311) and telecommunication equipment (SNI 322).[4] Medical equipment (SNI 331), electronic components (SNI 321) and optical equipment (SNI 334) are likewise characterized by positive transformation pressure and importance of scientific discovery, but are more characterized by a Mark I pattern. However, in many of these industries the main source of opportunities is not scientific advances but new technologies and materials. A second category can be exemplified by wood products (SNI 200), fabricated metal industries (e.g. SNI 281, SNI 287) and textile machinery equipment (SNI 29540) which are characterized by a Mark I pattern, but a less positive if not negative transformation pressure. Of these, in particular textiles and confection (SNI 170-190) and agricultural machinery (SNI 293) suffered a negative transformation pressure. These industries may be compared with Pavitt's (specialized and non-specialized) supplier-dominated industries. A third category consists of heavy process industries, such as basic metals (SNI 270) and pulp and paper (SNI 210), and the automotive industries (SNI 341 and 343). These industries fit well to Pavitt's description of scale intensive industries.

[4]These three product groups were dominated by Astra/Astra Zeneca and Pharmacia (SNI 244), Asea/ABB (SNI 311) and Ericsson/Sony Ericsson (SNI 322).

Table 5.3: Correlations between key variables, 48 manufacturing industries, 1970-2007.

	ΔQ	$\Delta INNO$	LARGE	SMALL	REC	TE	EC	ENV	ORG	NT	SCI	CUST	WORLD	NEW
ΔQ	1													
$\Delta INNO$	**0.41 [0]**	1												
LARGE	-0.05 [0.72]	-0.06 [0.69]	1											
SMALL	0.07 [0.64]	0.11 [0.48]	**-0.95 [0]**	1										
REC	0.22 [0.13]	0.08 [0.59]	**0.65 [0]**	**-0.51 [0]**	1									
TE	**0.44 [0]**	**0.5 [0]**	-0.19 [0.2]	0.17 [0.25]	0.15 [0.32]	1								
EC	**-0.36 [0.01]**	**-0.4 [0]**	-0.09 [0.54]	0.1 [0.51]	-0.11 [0.47]	**-0.36 [0.01]**	1							
ENV	-0.13 [0.38]	-0.17 [0.26]	0.14 [0.33]	-0.17 [0.26]	-0.09 [0.55]	-0.06 [0.66]	-0.13 [0.37]	1						
ORG	**-0.25 [0.08]**	-0.09 [0.56]	-0.17 [0.24]	0.23 [0.11]	**-0.31 [0.03]**	-0.24 [0.1]	0 [0.99]	-0.19 [0.2]	1					
NT	0.51 [0]	0.4 [0]	-0.19 [0.18]	**0.26 [0.07]**	0.24 [0.1]	**0.49 [0]**	**-0.39 [0.01]**	**-0.27 [0.06]**	**-0.34 [0.02]**	1				
SCI	**0.32 [0.03]**	**0.42 [0]**	**-0.44 [0]**	**0.45 [0]**	-0.16 [0.27]	**0.53 [0]**	**-0.25 [0.08]**	-0.14 [0.36]	-0.21 [0.15]	**0.54 [0]**	1			
CUST	**-0.38 [0.01]**	0.04 [0.81]	0.18 [0.23]	-0.13 [0.39]	0.18 [0.23]	-0.09 [0.55]	-0.13 [0.37]	**-0.25 [0.08]**	0.2 [0.17]	-0.08 [0.59]	-0.12 [0.42]	1		
WORLD	**0.44 [0]**	**0.53 [0]**	**-0.33 [0.02]**	**0.37 [0.01]**	-0.14 [0.34]	**0.3 [0.04]**	-0.16 [0.28]	-0.06 [0.71]	-0.14 [0.35]	**0.33 [0.02]**	**0.54 [0]**	**-0.29 [0.05]**	1	
NEW	**0.3 [0.04]**	**0.26 [0.07]**	-0.09 [0.56]	0.18 [0.23]	0.03 [0.84]	0.24 [0.1]	-0.08 [0.6]	0.06 [0.71]	-0.13 [0.36]	**0.32 [0.03]**	**0.38 [0.01]**	**-0.28 [0.05]**	**0.67 [0]**	1

Note: P-values within brackets. $P < 0.10$ are highlighted in bold.

Figure 5.5: Loading plot, first two principal components.

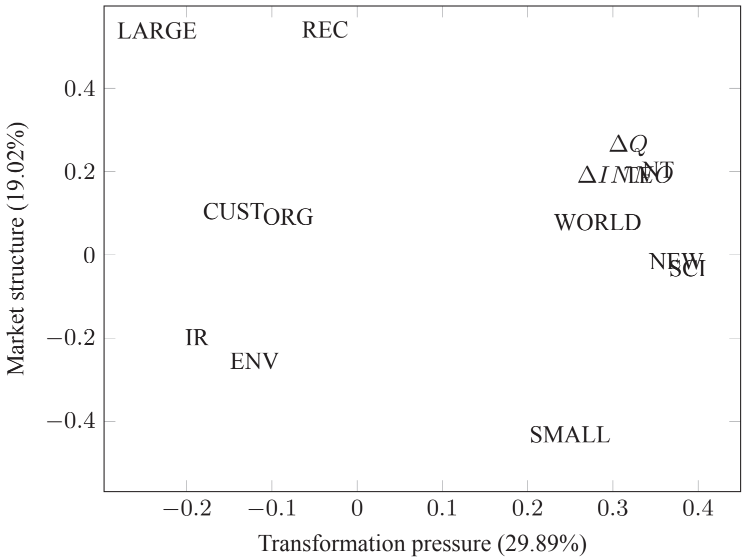


Figure 5.6: Score plot of industries (SNI codes) along the first two principal components.

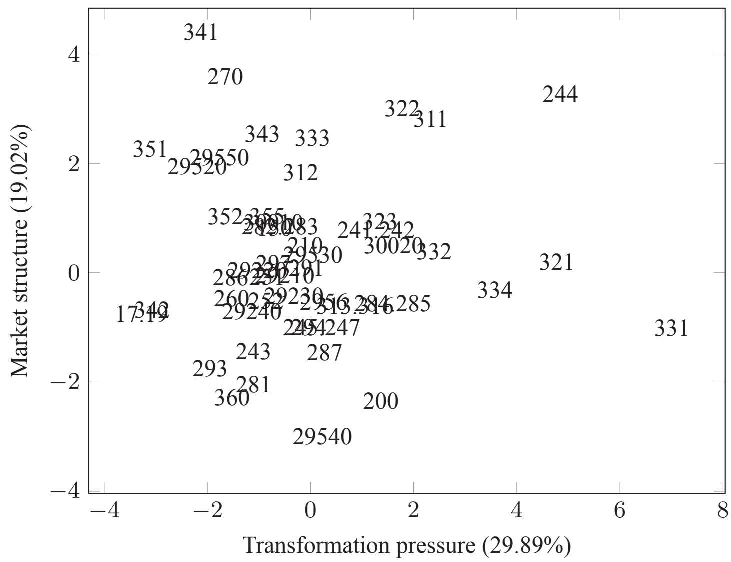


Table 5.4: PCA analysis. Loadings for the first three components.

Variables	Transformation pressure	Market structure	Environmental problems
ΔQ	**0.32**	0.22	
$\Delta INNO$	**0.32**	0.15	0.21
LARGE	-0.24	**0.49**	
SMALL	0.25	**-0.47**	
REC		**0.5**	
TE	**0.32**	0.15	0.13
EC	-0.19	-0.24	-0.22
ENV	-0.12	**-0.30**	**0.31**
ORG			-0.499
NT	**0.35**	0.17	0.17
SCI	**0.39**		
CUST	-0.15		**0.60**
NEW	**0.38**		-0.19
WORLD	0.28		**-0.30**
Variance	29.89%	19.02%	11.49%
Cumulative Variance	29.89%	48.91%	60.40%

Note: Only loadings $> |0.10|$ are shown. Loadings $> |0.30|$ are highlighted in bold.

5.4 Patterns of transformation pressure

The principal components analysis reveals that the main components of the differences across industries are summarized in transformation pressure and the market structure. The pattern of innovations and relative volumes over time and the types of transformation pressure appear to be related in a fundamental way. The analysis also shows that the variables measuring transformation pressure on the one hand, and firm size on the other, are only weakly correlated. Market structure has not been correlated with sources of transformation pressure or innovation performance over time.

The results suggest that particular patterns of innovation performance are shaped by transformation pressure. The remainder of this chapter examines more carefully the historical and unique patterns of transformation pressure across industries. In order to describe the main historical patterns of transformation pressure and creative response across industries, a classification of industries is constructed. The classification is consistent with the component scores of the first principal component, but aims to differentiate more carefully between industries on the basis of the patterns of value added volumes, innovation counts and the dominant sources of transformation pressure and the dominant types of innovation as creative response.

5.4.1 Innovation, growth and patterns of transformation pressure

The Dahménian taxonomy of advancing, stagnating and receding industries summarizes the long term relative volume patterns and the expected main type of transformation pressure (see Table 2.4). Advancing industries were argued to be likely to have a large number of innovations enabled by the exploitation of technological opportunities or motivated to resolve technological bottlenecks. In stagnating or receding industries, characterized by negative transformation pressure, innovation activity is rather assumed to have been oriented towards finding niche markets or toward solving economic, organizational or environmental problems.

Recently, Svensson Henning (2009) analysed the evolution of industries by volume patterns on the basis of the Dahmenian taxonomy for the period 1978-2007. A classification of industries has in the same spirit been carried out based on the long run patterns of value added volumes, the patterns of innovation counts and the sources of transformation pressure. As a basic classification, advancing industries have been defined as industries with more than 1 percentage point volume growth above the volume growth in the total manufacturing industry, 1970-2007. Stagnating industries are industries with between -1 and 1 percentage points volume growth above the aggregate industry growth rate. Receding industries are defined as industries with less than -1 percentage point relative volume growth.

A first classification has thus been made according to the economic performance of the industries in terms of advancing, stagnating and receding industries. Next, these groups have been categorized according to the type of creative response observable in terms of product innovations: 1) responding to positive factors (new technologies, scientific discovery or technological bottlenecks), 2) responding to negative factors (economic, environmental or organizational problems), or 3) failing to respond.

7 main types of industries have been discerned, labelled by a short descriptive. These categories are presented in Tables 5.5 and 5.6. Three distinct patterns were distinguished among the advancing industries. *Vigorously advancing industries* had a sustained increase in both relative volumes and counts of innovation during the period studied. These industries responded to a positive transformation pressure. *Stable advancing industries* are industries with increasing relative volumes, and a stable count of innovations over time. These industries have to a large extent responded to a negative transformation pressure. *Inhibited advancing industries* were industries with increasing relative volumes, but a decreasing count of innovations. Some of these were industries that, while characterized by strong opportunities during the first half of the period, have failed to transform or meet competition.

Table 5.5: Classification of industries according to relative volumes, innovation counts and transformation pressure. Advancing industries.

Industry groups	Vigorously Advancing	Stable advancing	Inhibited advancing
Relative volumes	>1 pp		
Industries	Pharmaceuticals (SNI 244), Electric motors (SNI 311), Electronic components (SNI 321), Apparatus for line telephony and line (SNI 322), Television and radio receivers, sound or video recording or reproducing apparatus (SNI 323), Medical and surgical equipment (331), Optical instruments (SNI 334), Forming and coating of metals (SNI 284-285)	Instruments for measuring, checking, testing, navigating and other (SNI 332), Motor vehicles (SNI 341), Parts and accessories for motor vehicles and their engines (SNI 343), Basic chemicals, pesticides and other agro-chemical products (SNI 241-242)	Plastic products (SNI 252), Other fabricated metal products (SNI 287), Electricity distribution and control apparatus (SNI 312), Industrial process control equipment (SNI 333), Bodies (coachwork) for motor vehicles; trailers and semi-railers (SNI 342), Computers (30020), Other electrical apparatus (SNI 313-316)
Technological opp. (NT)	52.65%	42.34%	41.89%
Techno-economic obst. (TE)	23.40%	7,47%	9,29%
Total positive (NT, TE, SCI)	63.80%	48.22%	46.17%
Work-environment (ORG)	2.56%	2.31%	6.78%
Environmental problems (ENV)	2.74%	14.77%	2.95%
Economic problems (EC)	3.66%	8.01%	10.62%
Total negative (ORG, ENV, EC)	8.96%	25.09%	20.35%
Total count	547	562	678

The vigorously advancing industries consisted of pharmaceuticals (SNI 244), telecommunication equipment (SNI 322 and SNI 323) and electronic components (321), optical equipment (SNI 334), electric motors (SNI 311), medical and surgical equipment (SNI 331), and forming and coating metals (SNI 284-285). In these industries, more than half of the innovations exploited technological opportunities and half of the innovations were entirely new to the firm. *Stable advancing industries* were measuring instruments (SNI 332), motor vehicles (SNI 341), parts for automotive vehicles (SNI 343), and basic chemicals and agro-chemical products (SNI 241-242). Somewhat less driven by technological opportunities, innovation activity in these industries was to a significant extent responding to negative transformation pressure, in particular pertaining to environmental problems. To the *Inhibited advancing industries* belongs e.g. computers (SNI 30020), which had increasing relative volumes until the crisis of the 1990s, but saw a decrease thereafter. The count of innovation increased until 1983, dropping thereafter to lower levels. These industries also comprised plastic products (SNI 252), electricity distribution and control apparatus (SNI 312) and the aggregated industry "other electrical apparatus" consisting of e.g. lamps, batteries and accumulators (SNI 313-316), which had increasing volumes but more or less secularly decreasing counts of innovations.

On the negative side of transformation, four groups are distinguished: *Followers* were industries with either stagnating or receding value added volumes, that had a *positive* or recovering count of innovations. *Responding* industries, the largest category, were stagnating industries in which negative transformation pressure took expression in creative response. Those stagnating industries that failed to respond to a negative transformation pressure have been labelled *Stagnating*. A final category captures the industries with starkly decreasing relative value added volumes, for which the term *Receding* has been retained.

Among the *Followers* were wood products (SNI 200) and machine-tools (SNI 294). The wood industry had a negative relative value added growth during the period studied, but saw an increase in innovation activity towards the end of the period. Machine-tools (SNI 294) was an important component of the third industrial revolution, but was crisis-struck during the 1990s. Production and innovation activity plummeted. An increase in the machine-tool innovations was however brought about towards the end of the period studied, in part driven by new technological opportunities.

Responding industries encompass large parts of the machinery industry, e.g. lifting and handling equipment (SNI 29220), and specialized machinery for e.g. paper and paperboard production (SNI 29550) and mining, quarrying and construction (SNI 29520). Many of these innovations were specialized suppliers solving problems in user industries. These innovations explain large parts of the surge during and following the structural crisis noted in chapter 4. *Stagnating* industries were those in which response to negative transformation pressure has been found only to a lesser extent: basic metals (SNI 270), food products (SNI 150), other special purpose machinery (SNI 29560) and office machinery (SNI 30010).

Examples of *Receding* industries were e.g. rubber products (SNI 251), shipbuilding (SNI 351) and agricultural and forestry machinery (SNI 293). These industries have typically had low counts of innovations or are concentrated to the first half of the period. A comparatively large share of these innovations were responding to a strong negative transformation pressure. This was particularly the case as regards agricultural and forestry machinery innovations.

These differences across industries summarize the main patterns of long-term and short-term transformation pressure. The analysis below describes the sources of transformation pressure across industries for a few of the industries concerned. The description is based upon the variables employed in this chapter and qualitative information available from the description of technological opportunities and problem-solving. The aim and purpose of the following sections is to describe and exemplify the types of problems and opportunities that historically have driven innovation activity in some of the industries categorized.

Table 5.6: Classification of industries according to relative volumes, innovation counts and transformation pressure. Stagnating and receding industries.

Industry groups	Followers	Responding	Stagnating	Receding
Relative volumes	<1 pp	-1 pp > <1 pp		< -1 pp
Industries	Wood and wood products, except furniture (SNI 200), Pulp, paper and paper products (SNI 210), Paints, varnishes and similar coatings, printing ink and mastics (SNI 243), Machine-tools (SNI 294), Other transport equipment (SNI 352-355)	Other non-metallic mineral products (SNI 260), Cutlery, tools and general hardware (SNI 286), Machinery for the production and use of mechanical power, except aircraft (SNI 291), Manufacturing n.e.c. (SNI 360), Furnaces and furnace burners (SNI 29210), Lifting and handling equipment (SNI 29220), Cooling and ventilation equipment (SNI 29230), Other general purpose machinery n.e.c. (SNI 29240), Machinery for mining, quarrying and construction (SNI 29520), Machinery for food, beverage and tobacco processing (SNI 29530), Machinery for textile, apparel and leather production (SNI 29540), Machinery for paper and paperboard production (SNI 29550)	Food products and beverages (SNI 150), Basic metals (SNI 270), Domestic appliances n.e.c. (SNI 297), Other special purpose machinery (SNI 29560), Office machinery (SNI 30010)	Rubber products (SNI 251), Structural metal products (SNI 281), Agricultural and forestry machinery (SNI 293), Building and repairing of ships and boats (SNI 351), Textiles, wearing apparel and leather (SNI 170-190), Other chemical products (including soap and detergents etc and man-made fibres) (sNI 245-247), Metal containers; central heating radiators; steam generators (SNI 282-283)
Technological opp. (NT)	28.78%	23.87%	31.59%	19.18%
Techno-economic obst. (TE)	3.86%	5.75%	7.21%	4.80%
Total Positive (NT, TE, SCI)	33.23%	28.51%	36.07%	22.88%
Work environment (ORG)	5.93%	7.40%	1.49%	8.12%
Environmental (ENV)	7.12%	17.13%	9.20%	11.81%
Economic problems (EC)	16,52%	13,05%	10,2%	18,45%
Total negative (ORG, ENV, EC)	29.68%	37.56%	21.11%	38.74%
Total	337	905	402	271

5.4.2 Advancing industries

5.4.2.1 Telecommunication industries

The information revolution has fundamentally shaped the industrial and technological development in the telecommunication equipment industry. Innovations in this industry have been by and large been driven by technological discontinuities such as the digitalization of switches or adapting components to emerging network communication systems or standards. The development of telecommunication equipment, and devices was in the first period (1970 - 1989) centered on a few larger actors, as was the development of the first mobile networks. The information revolution entered telecom technology through computerized control systems and digital switching technology. A previously mentioned important case is the modularized digital switching system "AXE" developed by the L M Ericsson and Ellemtel, launched in late 1976. The AXE system was a great success, spurring the development of other components, such as the SLIC circuit developed by RIFA to solve problems in the adaptation from analogue to digital switching technology.

During the 1980s and 1990s the opportunities created by the introduction of digital systems and the mobile telephony networks were becoming ample. Having overcome quality problems in the development of car and portable telephones, the first portable telephone designed for Nordic Mobile Telephone (NMT) was developed and launched by Ericsson in 1989 (Meurling & Jeans, 2000). The small size of the telephone was enabled by advances in the development of digital and analogue circuits made by Ericsson's mobile telephony division. The ensuing development of mobile telephones was likewise technology driven. The development of the GSM network (Global System for Mobile Service) enabled Ericsson to specialize in mobile telephone production.

While innovations launched by large firms (mainly Ericsson) were still dominating, the second half of the period saw a larger number of entrant or small firm innovators. New technologies, such as Bluetooth, and standards such as Ethernet, IP telephony, meant strong sources of opportunities for innovation. Meanwhile opportunities also existed in the shape of problems emerging in the development of the telecommunication and Internet infrastructure.

5.4.2.2 Electronic components

Following the increased opportunities in the deployment of Internet and telecommunication networks, development of electronic components were induced to solve capacity problems. The problem-solving innovations in electronic components can almost without exception be characterized as being aimed at enabling increased transmission capacity of telecommunication networks as it were, resolving bottlenecks that arose as the traffic volumes increased. For instance, problems with network processors, not living up to the requirements of fast routers, prompted Xelerated to launch a network processor capable of 40 Gbyte/second (commercialized 2006). The firm also developed the world's fastest programmable switching circuit for Ethernet. Other solutions were aimed at rationalizing the use of broad band, e.g. a file sharing technique in which all computers connected to the broadband network share broad band costs. Like in other advancing industries a shift most innovations during the second half were developed by small firms.

5.4.2.3 Pharmaceuticals and medical equipment

The advancing industries also contain what has been referred to as the 'biotechnology cluster', consisting of the pharmaceutical and medical and surgical equipment industries. The reader is referred to 4.4.3.3 for an in-depth description. As opposed to some other advancing industries these are characterized by a relatively high share of innovations based on scientific discoveries or academic spin-offs.

5.4.3 Stable advancers

5.4.3.1 The Automotive industry

Despite similar patterns of volume growth as telecommunications industries, the automotive industry and subcontractors tell a different story. A main difference with respect to other industries is the large firm dominance in innovation activity. A few large actors (e.g. Volvo and Saab-Scania) have developed a large share of these innovations. The introduction of computer aided production technology and electronics in cars were certainly sources of a positive transformation pressure. However, in terms of product innovations a more important source of transformation pressure in the development of automotive vehicles and parts were from the 1970s the increased social and political awareness of the adverse effects of fuel emissions. The increased oil, fuel and energy prices in the 1970s forced the automotive industry to concentrate efforts in this direction. Costumer-requirements, environmental awareness and sharpened legislation has since then also driven technological development in this direction (Elsässer, 1995; Bauner, 2007).

The sharpening of environmental regulations had and has continued to have an impact on emission control technology. This is reflected in the development of motor engine innovations (diesel or hybrid), hybrid cars or hybrid buses and in the development of alternative fuels that were aimed to attain lower emissions, saved energy in various ways (Elsässer, 1995, pp. 98-100). One of Saab's more significant innovations was its four-cylinder turbo engine that was presented in autumn 1976. The company's technicians showed that it was possible to combine low fuel consumption with high performance by using the turbocharging principle in a new way. In 1980 Saab presented the second generation turbocharged engine with the patented and award-winning APC system - Automatic Performance Control - which made it possible to utilize the fuel energy content maximally and to use fuels with different octane ratings without prior conversion (*Verkstäderna* 1980:4, p. 61).

Volvo was responsible for the development of several city buses in the beginning of the 1980s that were aimed to achieve lower energy consumption. One of these was a hybrid motor driven bus that achieved lower fuel consumption. Swedish Saab/Saab-Scania and Volvo have been internationally prominent in this development, and have developed a majority of the Swedish automotive motor innovations. However, the widely observed need for emission reduction and fuel efficiency has also generated innovation efforts beyond the manufacturers of motors.

The development of catalytic converters methods were likewise driven by stricter legislation in the U.S., Japan and Europe. Emissionsteknik AB struggled with known problems of catalysts, such as the accelerated oxidation of nitrogen monoxide to nitrogen dioxide that can produce toxic effects on people in urban areas.[5] The increasingly tougher emission limits in the U.S., Japan and Europe forced manufacturers of trucks to develop new recirculation technologies. One of these were EGR (Exhaust Gas recirculation) developed in the US as a response to stricter NO_x limits during the 1970s. Swedish firms have since integrated the technology into cars. Towards the 1990s and 2000s some Swedish innovators have developed the technology further, spurred by continued sharpening of the emission limits. A prob-

[5] Other known problems with catalytic converters was the accelerated formation of sulphates in the exhausts, which caused particle mutagenicity

lem with EGR has been that the exhaust gases have a lower pressure than the fresh air, which leads to increased fuel consumption. This problem was solved by two inventors starting up a new company Varivent, later bought by Haldex that came to commercialize the innovation (*Kemivärlden* 2003:8, p. 16; *Ny Teknik* 2003:1-3, p. 12; 2006:10, p. 4).

Another line of development in which Swedish automotive producers and subcontractors have specialized has been to increase safety in vehicles and to minimize personal damages in driving accidents. The three point seat belt was for instance a Swedish innovation. The development of innovations have likewise been influenced by new regulation. Autoliv is one of the most successful Swedish firms in this market niche. The WHIPS (Whiplash protection system) was developed by Autoliv in collaboration with Volvo Personvagnar, induced by the increasing problems with neck injuries in rear impacts at low speeds. The development was started in 1996 and the goal was to find a solution for Volvo's upcoming model S80. Likewise several innovations, such as the Airbag and WHIPS (Whipplash protection system) have been developed to come to terms with injuries from car accidents or even prevent car accidents.

5.4.3.2 Basic chemicals

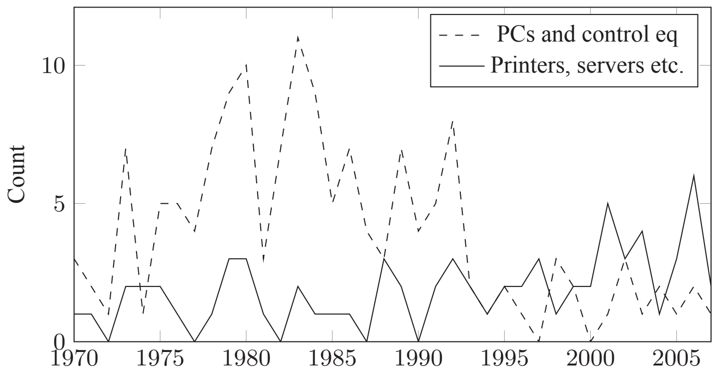
Parts of the chemical industry were affected by the oil and energy crisis and an increased awareness of the negative externalities. Of 55 basic chemical innovations, 25 were responding to a negative transformation pressure. The banishment of harmful chemical substances spurred firms to find replacement products. Following the oil crisis, the harmful effects of freons (also known as chlorofluorocarbons, CFC) and halogens on the ozone layer was brought to the attention of policy makers. CFC in spraying cans were prohibited in the late 1970s. In 1987 an international treaty (the Montreal protocol) was designed to phase out the use of CFC and other harmful chemicals (Bäckström et al., 1992, p. 116). In Sweden the use of CFC in all production was prohibited in 1995. These factors spurred search for new refrigerants (as well as cooling equipment innovations). For instance, AGA developed a freon-free refrigerant "Fryson" for applications in electronic component industries (*Elteknik* 1990:22, p. 39). Halogens were often used in fire extinguishers and flame retardants. The use of halogens was restricted by law in 1988, spurring several innovations. Bejaro developed a fire extinguishing medium without halon, called "halotron" (*Kemisk Tidskrift* 1993:1, pp. 42, 44). PP Polymer developed, among other innovations, "Paxymer"; a flame retardant aimed to replace the use of environmentally harmful halogens (*Kemivärlden* 2004:3, p. 5; *Kemivärlden Biotech med Kemisk Tidskrift* 2006:6, p. 8). Deflamo AB similarly developed a flame retardant (*Kemivärlden* 2005:2, p. 24; *NTT* 2004:28, p. 9; *Struktur* 2006:3, pp. 8-9).

5.4.4 Inhibited Advancers

5.4.4.1 Computers

Computers (30020) encompass personal and industry computers but also computer and information equipment such as scanners, printers, servers, modems and computer screens. Unlike the other industries playing a key role in the third industrial revolution, the computer industry has not had a sustained increase in innovation counts during the period studied. Innovation activity in this industry during the first half of the period has been described in chapter 4. The technological opportunities to exploit microelectronics technology dominated completely the early period. An early computer innovator was Saab that developed a minicomputer in the early 1960s, which later formed the basis of Datasaab. Other firms that developed computers during the 1970s were for instance MyData and Luxor that together with DIAB (Dataindustrier AB) and Scandia Metric developed ABC 80. All of these firms were acquired, sold, went bankrupt or cancelled their computer production before or during the crisis of the 1990s. Datasaab became unprofitable and was acquired in 1981 by Ericsson in the latter's failed move into business information systems (Ericsson Information Systems). Luxor was bought by Nokia in 1984, which cancelled Luxor's computer production in 1986 (see also chapter 7). The activities of Luxor were transferred to other parts of the Nokia corporate group or shut down in 1991. In short: the Swedish computer industry disappeared (Eliasson, 2001). Other computer products, e.g. control systems, followed a similar pattern during the 1980s and in particular after the crisis of the 1990s. After the crisis, volume growth and computer innovations decreased markedly. The pattern of computer innovations however shifted its focus from personal computers and factory automation towards other computer products for final consumption or the growing telecommunication and data communication industries, e.g. printers, servers and modems. This shift in the composition of computer innovations is shown in Figure 5.7. Among the later innovations, most were launched by a small firms. Two notable firms were Array Printers started in 1987 to develop and commercialize a printing technology, Toner Jet (invented by the founder Ove Larsson) and Axis Communications started in

Figure 5.7: Counts of PC and computerized control equipment innovations and printers, servers, modems and other computer-related innovations, 1970-2007.



1984 to develop and sell printer interfaces (for an in-depth description of Axis Communications, see Eneroth, 1997 and chapter 7).

5.4.4.2 Plastic products

The plastic products industry was expansive in terms of production volumes while however the innovation performance was declining throughout the period. In the first half of the period innovations were predominantly spurred by the emergence of needs or problems in other industries. Parts of the packaging industry is contained within the plastics industry. One of the major Swedish innovations during the post-war era was Tetra Pak, developed by Åkerlund & Rausing launched in 1951. It formed the basis of the firm with the same name. Tetra Pak launched two paper packaging innovations and seven plastic packaging innovations and seven others. Åkerlund & Rausing launched only one paper packaging innovation, 8 plastic packaging innovations and 4 others. An important user sector of plastic packaging innovations has been the foodstuff industry. Requirements from and problems emerging in the foodstuff industry have therefore influenced the development of new packaging innovations. Key requirements and problem areas were hygiene and temperature.[6]

[6]For instance, in the late 1970s a new Food act came into force with temperature restrictions, made difficult the distribution of goods with different temperature requirements. AB Smulan therefore in collaboration with Packforsk developed a roller pallet that gave longer shelf life to goods requiring cool storage (*Livsmedelsteknik* 1979:1 p. 41; *Kemisk Tidskrift* 1979:2, p. 15). Another example is a new yoghurt packing that resulted from a research study claiming that the current packings left contents for over half a billion SEK in

A theme in innovation activity in the plastic industry has otherwise been the exploitation of distinct advantages of plastic materials over other types of materials. Several plastic innovations have been developed to exploit material advantages over steel constructions, enabling lighter constructions and flexibility. For instance, Strömberg Engineering developed a ship propeller made of plastic based on the ideas of inventor Karl-Otto Strömberg: "Until now ship propellers have been made of steel or bronze. Any attempts to use lighter and less stiff materials have failed" (*Ny Teknik* 1991:41, p. 16; *Verkstäderna* 1992:5, pp. 62-64; *Plastforum Scandinavia* 1992:3, p. 20). There were even examples of air planes and bicycles built in plastic materials.

5.4.5 Followers

5.4.5.1 Machine tools

144 machine tool innovations were launched during the period studied. The innovation activity is concentrated to the 1970s and the early 1980s and exhibited a downward trend until the late 1990s. Machine tool innovations can be considered part of a broader development block in factory automation involving also control systems, automatic guided vehicles and industry robots. The development of machine tools on the international scale has been characterized by the introduction of numeric control systems (from the 1960s), computer numeric control systems (from the 1970s) and PC based control systems beginning in the 1990s (Arnold, 2001). Despite the strong technological opportunities that have characterized the industry, the relative volume growth of the Swedish machine tool industry has been negative over the period studied. During the crisis of the 1990s several firms in the industry were hit hard and the prospects of the Swedish industry was uncertain. Most firms in the machine tool industry were competing on the international market and the industry was thus export dependent. Swedish suppliers of numerically controlled machine tools and flexible manufacturing systems were forced out of business in the 1990s by the Japanese competitors (Carlsson & Jacobsson, 1997; Ehrnberg & Jacobsson, 1995, p. 42). Japanese competitors were able to obtain a substantial competitive advantage by developing small, standarized machines for broad purposes, while Western manufacturers were more oriented towards large, complex and specialized machines (Carlsson & Jacobsson, 1997, p. 42).

the packings. In this case, Arla contracted Tetra Pak to solve the problem.

A notable Swedish firm in the machine-tool industry was SMT Machine Company.[7] After a crisis in 1970 SMT Machine company decided to specialize in producing CNC lathes. The company had developed its own numeric control system "CNC 210", which was developed further and used in its machine tool innovations (*Automation* 1973:3, pp. 54-55). A CNC controlled lathe was launched in 1974 (*Verkstäderna* 1974:9, p. 24; 1975:1, p. 24) and a CNC lathe in 1977 (*Verkstäderna* 1977:10, pp. 59-60). This decision paid off in terms of rising profits. At the end of the 1970s competition from Japan eroded profits and SMT went from gains to losses. SMT began at this time to develop auxiliary systems for CNC lathes (Ehrnberg, 1995, pp. 306-307). In 1980 the firm launched a computerized part changer, a machine that changed parts in companies' lathes (*Ny Teknik* 1980:22, p. 8). According to Ehrnberg & Jacobsson (1995) the CNC production declined throughout the 1980s as SMT was unable to differentiate itself from German and Japanese competitors. SMT was one of the firms struck by crisis in the 1990s.

Machine-tool innovations have primarily been shaped by technological opportunities, but machine tools were also to a non-negligible extent developed to solve techno-economic problems downstream, for the wood industry during the structural crisis in particular and to the engineering industries in general. Irrational costs were eliminated and problems in the work environment were solved by automation of manual or costly operations. Industry noise and vibrations were in several cases dealt with by machine tool innovations, e.g. a sander developed by Rikard Johansson Maskin AB in collaboration with Bofors AB to reduce noise and dust problems (*Verkstäderna* 1977:3, pp. 30-2). Centro-Maskin Göteborg AB launched an innovation to automate the manual task of planing cracks in steels, one of the hardest in steel mills (*Ny Teknik* 1977:31, p. 22). Machinery to produce chip wood from stumps and waste wood was launched in 1975 by Piteå Maskinindustri AB as a response to the wood shortage (*Sågverken* 1975:11, p. 839). At the basis of AB UVA's machine innovations lay a microcomputer based control system (called Uvatronic) developed by the firm. UVA launched two innovations: a CNC controlled machine that solved grinding problems in the automotive industry and a grinder machine for several operation (*Verkstäderna* 1983:5, p. 34; *Verkstäderna* 1986:14, p. 44-47).

As a result of entrant firms and incumbent firms developing innovations based on new technology, a resurgence in the count of machine tool

[7] The description of the company history is based on Ehrnberg & Jacobsson (1995, pp. 306-308).

innovations and volume growth could be observed towards the end of the period. The surge in machine tool innovations towards the end of the period can in part be explained by a set of entrant firms developing machinery for wood production and other firms exploiting various new technological opportunities. Morphic Technologies (*Verkstäderna* 2003:4, pp. 14-16) and Hydropulsor (*Verkstäderna* 1999:5, pp. 33-34; 2005:2, p. 26) were firms that exploited the technique of so-called "adiabatic forming".[8] Lidköping Machine Tools launched an innovation in 2005 that was the result of ten years of development work: "Nano Grinder", capable of precision grinding at the nano-level.

5.4.5.2 Wood and wood products

The wood sector suffered a raw material shortage during the 1970s. This not only induced countermeasures in the wood industry but also among producers of forestry machinery (see chapter 6). The case of Masonite AB and its building system is an example of the response in the industry. Masonite AB changed its marketing aims and started R&D efforts in 1973 due to the energy crisis, wood shortage and soaring wood prices to develop a building system enabling economizing of wood raw material.[9] Other innovations during this period were creative responses aiming to economize on the use of wood in the production of wood products.

In the later half of the period a resurgence in wood product innovations occurred. It is difficult to explain this surge in terms of the emergence of new technological opportunities. However one may note that a large ma-

[8]The first generation machines employing this technique came in the 1960s, working with compressed air. The new machines used hydraulics. Morphic claimed that they had solved the technological obstacle of obtaining enough speed in the hydraulic valves and thereby controlling the blows (*Verkstäderna* 2003:4, pp. 14-16).

[9]"The raw material shortage and energy crisis made many forest industry men wonder what the future had in store. The shortage of timber will probably lead to a radical change in the use of wood based materials for building purposes. When standing timber prices rise, new technical-economic solutions of the problems are developed by the application of new constructions and new materials. It is most likely that to a higher degree than is the case today the constructions will include several combinations of material in which optimum advantage will be taken of the properties of the respective materials. The difficulties resulting from the energy crisis induced Masonite AB to set up new production and marketing aims and to conduct a new policy accordingly. In 1973, with financial support from the Norrland Development Fund, the company started intensive research and development work. Enthusiasm jointly with know-how brought about the new building system, which promises revolutionary innovations" (*Svensk Trävaru- och Pappersmassetidning* 1976:7, pp. 539-544).

jority of innovations in this surge were developed by small firms.

5.4.5.3 Pulp and paper

Pulp and paper innovations were 61 during the period studied. The product innovations launched were with only a few exceptions innovations in the fields of paper packaging and paper products. In the first period, 1970-1989 the pulp and paper industry was under a negative transformation pressure, and innovation activity was directed towards the developing new production methods and dealing with negative production externalities. This involved a larger amount of innovations, most of which were paper and pulp machinery, measuring equipment products and new methods. Towards the end of the period there were examples of paper innovations based on electronic technologies. These innovations exemplify how new technologies may be the answer to a fundamentally negative transformation pressure, the replacement of traditional paper media with electronic media. There were for instance efforts aimed to develop "electronic paper" and electronic packs (e.g. for foodstuff). One example was Addmarkable that in cooperation with SCA developed and commercialized a touch sensitive paper.[10] SCA also developed a touch-screen display as a part of a research project taking part at the Mid Sweden University (*Svensk Papperstidning* 2007:8, pp. 18-19). Stora Enso's "electric adhesive" (called CDM, controlled delaminated material) that comes off on command was cited as a revolutionary innovation in the packaging industry. It was launched after the end of the period studied (in 2008) (*Svensk Papperstidning* 2006:7, p. 8; *Ny Teknik* 2006:37, p. 6; 2007:12, p. 32).

Organoclick developed a waterproof paper, based on a catalytic process that enabled cellulose to be used for composite impregnation of wood so that it is made resistant to rot, or to make cotton fabric water repellent. The underlying process was developed by a scientist at Stockholm university and one of Organoclicks co-founders.

[10] "The principle is to press the paper and board with colors that conducts electricity. This means that the paper surface can be made touch sensitive. By then connecting this sensor to a device that plays sound or generates light or color, you can create a paper that responds to your touch" (*Svensk Papperstidning* November 2004, p. 40; translation by the author).

5.4.6 Responding industries

5.4.6.1 Heatings pumps, cooling and ventilation equipment

Several innovations pertaining to cooling, ventilation, heat and energy distribution were responding to the changed conditions that followed from the oil crisis.[11] Heating pumps were developed and diffused rapidly after the structural crisis of the 1970s. The oil crisis and the increased energy prices contributed to make heating pumps an economically feasible alternative (Kaijser et al., 1988, pp. 76-92). The heating pump technology reinforced and enabled established energy distribution systems, electric heating and district heating to be developed further (see secttion 6.4.2.3 for further discussion). Similarly, heating recovery systems for domestic and industrial use were developed to enable better energy economy. AB Svenska Fläktfabriken launched several innovations that were aimed to overcome critical problems in attaining energy savings in heating recovery systems. Other ventilation innovations responded to problems in the working environment involving dusting and toxic fumes. Many of the cooling innovations solved problems emerging in the introduction and use of freezing and cooling technologies for foodstuff. In particular, these innovations solved critical problems that hindered the distribution of Quick Freezing technologies (see chapter 6).

5.4.6.2 Lifting and handling equipment

The lifting and handling industry had stagnating volumes but rather stable counts of innovations over the period. Innovations in lifting and handling equipment (SNI 29220) were characterized both by problem-solving and by having exploited opportunities stemming from industry automation and microelectronics for innovation, also towards the end of the period. The category also contains industrial robots aimed for material, storage and handling (for some of these innovations, see discussion on page 105).

The problem-solving activities of producers of lifting and handling equipment have been influenced by problems in user industries. Thus, these innovations have responded to negative factors downstream. Some innovations, especially lifting trucks, were developed to solve problems in the work-environment. Kalmar LMV developed a flywheel powered truck with the goal to reduce exhausts in the work environment in the loading and un-

[11] Heating pumps for domestic use were part of the category 'furnaces and furnace burners' (SNI 29210), whereas heating pumps for industrial use are part of the category 'cooling and ventilation equipment' (SNI 29230).

loading of ro/ro vessels and in freight terminals (*Verkstäderna* 1983:12, pp. 52-53; *Transport Teknik* 1983:5, p.14). Exhausts and occupational injuries were also the reasons for the introduction of new vehicles in mining industry (compare also Saab Scania's unmanned vehicle, described on page 113). To solve problems in the work-environment, Kiruna Truck developed an electric truck, a part of a larger transport system for the mining sector (*Jernkontorets Annaler* 1985:4, p. 77; *Ny Teknik* 1985:41, p. 59). Similarly, ergonomy and security have been major focuses of several of Atlet AB's innovations.

Other major innovations in this field were based on solving economic problems emerging in transportation of goods. SKF for instance launched a conveyor "Flex-Link", originally developed as a project to solve problems regarding efficiency in transportation within SKF in the beginning of the 1970s when the firm was undergoing a period of structural change and lay-offs. The conveyor came in commercial use in 1979 and became the seed to the firm bearing the same name (*Skandinavisk Transport Teknik* 1987:3, pp. 38-40).

The innovations launched towards the end of the period were frequently aimed at automation or solving economic problems. ABB launched 9 industrial robots aimed for storage and material handling during the 1990s and 2000s. Other firms launching several innovations during the 2000s were Atlet, BT Industrier, Max Move Industrier and Moving AB. The two former launched several fork lifts and other vehicles for lifting and handling. Max Move Industries and its innovations were based on the "Max wheel", an innovation by Max Segerljung, that enabled trucks to rotate 360 degrees (*Ny Teknik* 1989:13, p. 20; *Transport idag* 1994:5 p. 28-31; 2004:5, p. 20; 2004:12, p. 15; 2005:17, p. 19). Moving AB was specialized in automated storage and handling equipment, launching among others a module system for material handling based on a new microprocessor control system (*Transport idag* 2004:10, pp. 18-19) and a robot-based system for transportation (*Transport idag* 2003:15, p. 27).

5.4.6.3 Textile machinery

See description of textiles in section 5.4.8.2.

5.4.7 Stagnating industries

5.4.7.1 Basic metals

The steel industry was one of the industries hardest hit by the structural crisis of the 1970s. The crisis had structural reasons on an international scale. A rapid productivity increase in conjunction with less demand for steel constructions in investment projects created a global over-production of steel. The relative decline of steel demanding investments, was connected to the increasing importance of electronics (Fritz, 1997, pp. 105-108). Swedish steel industry was hit particularly hard in part due to the crisis and decreased investment in important sectors downstream, notably the engineering and shipbuilding industries. Another important factor was the over-optimism during the beginning of the 1970s that led to the initiation of (irreversible) investment projects that effectively hindered steel mills to deal with their over-capacity (Fritz, 1997). One of the most important explanations of the long term relative decline of the steel products was the replacement of mechanical parts in industrial products with electronics. Another is the improved quality and strength of steel that has implies that lower volumes have become necessary for certain applications.

The structural crisis forced the industry to restructure. The crisis induced innovation as creative response in several ways, though not in large numbers of product innovations. There are however a few examples of product innovation. SSAB (Svenskt Stål AB) was formed from the Domnarvet, Norrbotten (NJA) and Oxelösund ironworks. After the formation of SSAB in 1978, Oxelösund faced a problem to find a market for half a million tonnes of heavy plates in new business segments. To accomplish this, SSAB decided to develop highly abrasion resistant heavy plates for machinery and steel constructions that resulted in the launching of the two commercially successful product families HARDOX and WELDOX (*Bergsmannen med Jernkontorets Annaler* 1995:7, pp. 16-20; 1999:3, p. 101; 2002:1, p. 14).

Another example was SKF, mainly a producer of roller bearings. SKF became burdened by its steel divisions and reorganized its steel production into a new company, SKF Steel AB. Due to the structural crisis, efforts were made to develop new products. The main project was the plasma process project that attempted to solve a problem of shortage of scrap iron that had emerged due to the fact that many iron mills had replaced martin production facilities with electro-steel methods that were entirely based on scrap iron. The development of SKF Steel's Plasma technologies were in part an attempt to replace scrap with sponge iron (Fritz & Karlsson, 2006, pp.

278-280). The technologies were also developed and exploited to solve the steel industry's environmental problems, launching a method for recycling of dust from iron and steel mills. Methods of treating dust through metal recovery had previously failed for cost reasons (*Kemisk Tidskrift* 1982:8, p. 14; *Jernkontorets Annaler* 1983:2, pp. 22-23; *Ny Teknik* 1983:52, p. 35).

Apart from these and a few other examples, the development of steel products has followed certain problem-solving trajectories that are connected to the structural conditions of steel production. The long term relative decline of steel products has directed steel towards markets such as construction and automotive vehicles. Steel varieties have been developed in particular to improve strength and enable lighter steel constructions. Pertinent problems in attaining this have been abrasion and segregation. One major advance in steel production was the ASEA-STORA process, developed by Stora Kopparbergs AB in collaboration with Asea. It was aimed to solve the costly problem of segregation (*Ny Teknik* 1970:23, pp. 9-10; *Verkstäderna* 1970:8, p. 431; *Kemisk Tidskrift* 1973:6, p. 10; 1977:4, p. 20).[12] The steel (called ASP) was launched in 1973.

The trajectories of improving strength and decrease the weight have continued to be important in the development of new steel products. However, during the later half of the period, some innovations reflected search for new markets. Demands for better steels for suture needles and the discovery of quasi-crystals in 1984, prompted Sandvik Steel to develop a new steel reinforced with quasi-crystals. The problem to be overcome was that thinner and stronger needles were necessary to make the eye and heart surgery safer and bring plastic surgery forward. The steel was launched in 1999.[13] In the 1990s, while most innovations were developed by incumbent firms, there were also a few entrants on the steel market, e.g. Duroc and Accra. Accra was started in 1994, exploiting a new process that enabled the pro-

[12]The development was started in 1965 in Söderfors. Asea was involved in 1968 (*Ny Teknik* 1977:29, p. 9). The background was described as follows: "A problem with high-speed steel and other alloy steels is their strong tendency for segregation. This phenomenon, which is a natural result of the metallurgical process in steel manufacture, has so far been difficult to deal with. Segregation can be prevented if the ingot is cooled very quickly. The required cooling rate, however, is so large that in practice can only be achieved if the ingots are very small [...] i.e. forming a powder. This relationship constitutes the background to the new manufacturing method" (*Verkstäderna* 1970:8, p. 431; translation by the author).

[13]Despite being so thin, they must never bent or break, even when they are used to sew the heart's tough tissues. Previously, drilling technology limited hardness of the material and hence the dimensions of the needle and thread (Ny Teknik 1999:4, p. 17; Verkstäderna 1999:3, pp. 16-17).

duction of steel details for the automotive industry able to compete with aluminum (*Ny Teknik* 1999:49, p. 14).

5.4.8 Receding industries

5.4.8.1 Shipbuilding

The shipbuilding industry was one of the industries hit hardest by the structural crisis of the 1970s. One reason for the severity of the crisis was the specialized industry structure in Swedish shipbuilding. During the post-war era the the industrial growth in Japan was a central factor behind the increased demand for transoceanic tankers and bulk shipping (Ljungberg, 1985, p. 21; Olsson, 1998). The first oil crisis in 1973-1974 led to increased oil prices, which decreased oil transportation and the demand for tankers. A contributing factor to the crisis at that point was also the commencement of oil extraction in the North Sea, which decreased the transport routes and thereby the orders. This situation was worsened by the over-optimistic investments carried out in the first years of the 1970s (Ljungberg, 1981, pp. 70-72). An overcapacity developed in the following years. Svenska Varv AB, a government owned company, was formed in 1977 to support the crisis-ridden industry. The aim was to successively diminish the support until 1984 and dismantle the shipbuilding companies that were unprofitable. It came to overtake several troubled shipbuilding companies in the following two years. Kockums, the last independent large shipbuilding company, was bought in 1979.

The shipbuilding crisis intensified the need for reorientation of production. The expansion of offshore drilling in the North Sea emerged as an alternative market (Olsson, 1998). Already in the beginning of the 1970s, Kockums developed and launched two submarines for use in the exploitation of oil deposits discovered in the North Sea. Oil drilling in the North Sea had proven difficult to due weather conditions and rough sea, and there was a great need to enable the use of surface vessels as mother ships. Kockums therefore developed a submarine system that was weather independent (*Ny Teknik* 1975:18, p. 8; *Verkstäderna* 1975:9, p. 43, *Transport Teknik* 1976:6, p. 181; *Automation* 1977:7, pp. 36-37).[14] Similarly, Öre-

[14]Surface ships were very weather sensitive. The North Sea being is one of the most difficult with often severe storms and very rough sea with often 20 meters high waves. Here a submarine system with surface vessels could not used more than approximately 100 days a year. The corresponding figure for the new system was expected to be about 300 days.

sundsvarvet launched an off-shore "multi-purpose vessel" (*Transport Teknik* 1980:1, pp. 20-21; *Verkstäderna* 1980:4, pp. 62-64).

The plan approved by Svenska Varv AB's board in January 1980 suggested a division of labor between the remaining large shipyards. Uddevallavarvet and Kockums would be responsible for production of tankers, bulks and unit cargo ships (Olsson, 1998, p. 218). Götaverken Arendal shipyard would concentrate on offshore products. Götaverken Arendal Cityvarvet had developed *Safe Astoria*, a semi-submersible platform for offshore drilling, which was the company's step into the offshore market (*Verkstäderna* 1978:12, pp. 60-61). Kockums however saw an opportunity to enter the offshore market in 1981 by developing submarines and underwater technology, e.g. an underwater habitat (Olsson, 1998, p. 221; Ny Teknik 1981:40, p. 32). Kockums was also developing a hydrophone measuring system to detect subsea cracks in offshore drilling rigs. The need for such a system had become apparent when in 1980 the Norwegian rig Alexander Kielland was hit by a storm and capsized. The cause of the accident was believed to be cracks in the rig below the surface (*Ny Teknik* 1981:40, p. 32).

The military sector has remained important for shipbuilding companies after the crisis. The marine defense has been of a central importance in the development of ship and submarine innovations. Kockum's production of trade ships ceased in 1987, leaving Kockums Marine that was specialized in submarines (Olsson, 1998, p. 213). Karlskronavarvet made several developing ships for removal of mines. Among its more successful vessels was the Landsort series (*Plastforum Scandinavia* 1984:4, pp. 110-111; *Verkstäderna* 1984:8, pp. 52-55). Towards the end of the period, the remaining shipbuilding innovations were few and almost exclusively developed for military purposes.

5.4.8.2 Textile and clothing products. Textile machinery.

Textile and clothing innovations (SNI 170, 180 and 190) were few. During the whole period these three industries amounted to 30 innovations. For the textile industry the structural crisis of the 1970s, like in most other West-European countries, meant rationalizations and a decimation in the employment and production of textiles. During the 1970s, a few textile innovations were responses to these changing conditions. A new textile material was the response to the cotton shortage: "What forced the development of a replace-

(*Ny Teknik* 1975:18, p. 8; *Verkstäderna* 1975:9, p. 43, *Transport Teknik* 1976:6, p. 181; *Automation* 1977:7, pp. 36-37).

ment for cotton is the world's cotton crisis - the availability decreases all the time. In the textile industry it is feared that there is not even any cotton to buy in a few years" (*Ny Teknik* 1976:9, pp. 1, 4-5).[15] Demands for a better work environment was also the source of the development of a few clothing innovations during the 1970s and early 1980s. One development project involved a large number of Swedish firms in the engineering and textile industries, the Swedish Metal Workers Union and STU and resulted in new uniforms for the engineering industry (launched 1981). In autumn 1976 SKF in Gothenburg had expressed a desire to STU to get help with acquiring new uniforms primarily for their automatic turners that are often exposed to cutting oils. Several companies in the engineering industry in Gothenburg had similar problems and wished to participate in a development project. As a result of these requests, guidelines were drawn up for a joint development project (*Verkstäderna* 1981:1, pp. 10-12). A similar example was Tretorn that developed protective boots due to the high risk for occupational injuries in forestry work (e.g. accidents in felling and involving chain saws)(*Sågverken* 1974:2, p. 121).

Some textile and clothing innovations towards the end of the period made use of new technologies, finding niche market opportunities.[16]

Investment activity in the textile and clothing industry was in the mid 1980s described as primarily directed towards expanded production capacity abroad, rationalisations or marketing (Erlandsson, 1985, p. 273). The development of textile machinery innovations was thus focused on automation, eliminating bottlenecks and irrational (manual) working moments and introducing computer technology. One problem was the wrinkling of clothes during production and transportation. A significant textile machinery innovation "Tex Vac" was the result of projects TEFO had worked with in the 1960s to solve the problem with wrinkling of clothes during transportation, and research on the impact of temperature on the properties of textiles (made by Roshan Shishoo).[17] Swematex developed a similar method called Tex

[15]The reason why the availability of cotton decreased was that land previously used for cotton production was increasingly used for agriculture, e.g. soy beans.

[16]For instance, Jörgen Lillieroth started Comfort Cooling AB in 1994. One of the first products was a body armor used by fire fighters to attenuate exposure to heat. The cooling effect comes from it in the vest is sewn slabs of a material that changes its structure when heated. In 2007 the firm launched a cooling pad that cools laptop computers (*Verkstäderna* 2007:5, pp. 46-47). Another firm, AB Ludvig Svensson was started to develop sound dampening fabrics of flame-resistant polyester (Verkstäderna 2007:5, pp. 46-47).

[17]The innovation is among the 100 significant innovations cited by Wallmark & McQueen (1988, 1991).

VPS (*Textil och konfektion* 1983:4, p. 14).

Computer aided machinery innovations were also made, e.g. for the cutting of textiles. Due to bottlenecks in the cutting of textiles, Konfektionsdata developed an early computer controlled laser cutting machinery, in collaboration with Saab-Scania (*Ny Teknik* 1972:2, p. 1). The world's first computer controlled laser cutting machine for sails was developed by the inventor Gunnar Knutsson and Thomas Söderling and launched by Datamönster AB (*Automation* 1983:5, pp. 37-38). AB Calator developed the world's first automatic shirt buttoning machine (*Ny Teknik* 1977:40 p. 26).

5.4.8.3 Rubber products

Facing declining relative volumes, innovation activity in the rubber industry transformed from a dominance of larger firms to small entrepreneurs towards the end of the period. The six largest firms in terms of sales and employees in 1983 were Trelleborg AB, Gislaved, Forsheda, Skega, Tretorn and Viskafors (Brandt, 1985, pp. 301-302). Out of 42 rubber innovations Trelleborg AB developed 8, Gislaved 3, Forsheda 2, Skega 4 and Viskafors 1. Tretorn developed two rubber boots innovations that are classified as footwear (SNI 19300). The innovations were from the 1980s to a larger extent developed by inventor-firms or smaller firms having identified a market niche or a techno-economic problem that can be solved by using rubber materials.[18]

Rubber material innovations have found applications as vibration and sound dampeners. For instance, rubber materials have vibration dampening properties that were used to appease work-related injuries from drilling machines in the mining, forestry and construction sectors. A rubber lining was developed by Trelleborg together with FOA (Försvarets forskningsanstalt) to eliminate vibrations and noise in the work environment of ship crews (*Ny Teknik* 1981:19, pp. 16-17). Another example is Rubore Materials that anticipated a need to dampen sounds for brake linings after car producers replaced asbestos brake liners during the 1980s.[19] A rubber wear plate aimed

[18] Inventor-firms include Jan-Olov Nordberg that developed a rubber sole for cross country skiing designed to keep warmth (*Ny Teknik* 1983:11, p. 4), Tooling Promotion that launched a rubber band for tennis rackets (*Ny Teknik* 1987:22, p. 8) and Dahl Polymers AB (*Ny Teknik* 2004:38, p. 5) that launched an air cushion developed by the inventor Roger Dahl. Rubore Materials was started in 1988 to exploit inventions by Percy Josephsson. It was later bought by Trelleborg (*Plastforum Scandinavia* 1993:9, pp. 32-33). See also below. Refine AB Labels was started in 2005.

[19] "The reason for the company's rapid growth is primarily their own development of vibration absorbers for automobile brakes. The asbestos brake linings in cars were replaced

to reduce wear and abrasion problems for dump trucks and other vehicles in the transportation of rock, gravel and other abrasive material was developed by Skega.[20]

The problem of recycling of rubber and tires prompted the development of a few new rubber methods and products. For instance, Stockholm Trade Company AB developed a production method of rubber mass from scrap tires (*Verkstäderna* 1986:15, p. 50). In Trelleborg's recycling method bacteria liberate sulphur in scrap tires, which made it possible to mix the scrap rubber into new rubber products without impairing the material properties. The method thereby overcome technical difficulties in the de-vulcanization of scrap tires (*Ny Teknik* 1996:3, p. 5). JLP developed a method for recycling of rubber (*Plastforum Scandinavia* 1983:11, pp. 39-40).

5.4.8.4 Agriculture and forestry machinery

Agriculture and forestry machinery innovations responded to the acute wood shortage and unprofitability in the forestry sector during the 1970s and 1980s (see chapter 4 and section 6.4.5). These innovations were aimed to improve profitability in the handling and cutting of wood, much like wood products and production systems were aimed to reduce wood spill.

5.5 Conclusions

This chapter has investigated the patterns of innovation across industries as concerns the type of innovating firms and the origin of innovation in terms of creative response to technological opportunities and economic, environmental and organizational problems. In a first part, the main differences across industries were discussed. The results indicate that the industry dy-

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in the 1980's with today's materials, which were found to have some undesirable characteristics: they cause shrieking sounds. 'I had worked with the brakes earlier and knew that there would be a need for some sort of moderation,' says Percy Josefsson, CEO at Rubore Materials and the man who developed Rubore concept" (*Plastforum Scandinavia* 1993:9, pp. 32-33; translation by the author).

[20]The construction industry had major problems with adhesion of material. In particular, it was the industry's increased use of concrete as a building material, which created problems. The materials that cause the biggest problems in the transport and loading sector, were described as clays and earth deposits, which at a certain moisture stick to the platform or bucket. In the northern climate of Sweden, it was not just sticking that was a problem, but also the freezing of the material (*Transport Teknik* 1970:9, pp. 530-531; 1971:1, pp. 60-63).

namics in the long run correspond *in general* to different patterns of transformation pressure. Principal components analysis (PCA) revealed three main groups of industries along two main dimensions: market structure and transformation pressure. One group of industries had a strong positive transformation pressure. Some of these had a Mark II pattern of innovation (in particular pharmaceuticals, electric motors and telecommunication equipment. Others were more characterized by a Mark I pattern (e.g. medical equipment, electronic components and optical equipment). A second group of industries were reminiscent of Pavitt's supplier-dominated industries, responding mainly to a negative transformation pressure. A third group consisted of heavy process industries dominated by large firms and trajectories towards solving economic or environmental problems.

A second part analysed more carefully the patterns of transformation pressure across industries. The results found support for the general notion that industries with increasing relative volumes and counts of innovation to a large extent have been driven by strong technological opportunities and solving problems hindering the diffusion and exploitation of these new technological opportunities. Conversely, industries characterized by stagnating or decreasing relative volumes on the other hand have had decreasing counts of innovation and problem-solving activity has been directed towards solving production bottlenecks and irrational costs. However the qualitative analysis also revealed different types of innovation trajectories among advancing industries and different types of responses to negative transformation pressure.

Among the advancing industries, were for instance the basic chemical and automotive industries in which new technologies and materials were driving innovation to a non-negligible extent, but where environmental and other problems have been more salient contributing factors influencing the long run technological trajectories of the industries. Other industries labelled "inhibited advancing" industries, had increasing relative volumes, but sharply declining counts of innovation. The computer and plastics industries were among these industries.

Among the stagnating and receding industries there were considerably different responses to negative transformation pressure. In some industries, labelled "responding" industries, there was a comparatively large number of innovations, responding to environmental, economic or organizational problems. Most of these were machinery innovations, many of which were solving problems in user industries. The shipbuilding, basic metals, rubber and textiles industries, each give examples of different patterns of innovation. The pattern of creative response in the shipbuilding industry mostly took expression in diversification and attempts to enter other markets. Textile and clothing innovations were few. Some textile and clothing innovations towards the end of the period made use of new technologies, finding niche market opportunities. Rubber products competed on the basis of niche markets where rubber had superior qualities due to its flexibility. The basic metals industry by contrast was not responding to a great extent in terms of new product innovations. Rather, the response was geared towards large scale process innovations.

In sum, the results of this chapter suggest the existence of a general correspondence between transformation pressure and innovation performance. However, as suggested by historical descriptions, the actual response has varied and has ultimately been determined by historical circumstances that allow some industries to solve problems and transform, while others have waned - even disappeared.

6. Development Blocks and Intersectoral Determinants of Innovation in Swedish Manufacturing, 1970-2007

6.1 Introduction

In this chapter I set out to describe and analyse *intersectoral* determinants of innovation and technology shifts. The task is to examine how the previously found industry-level patterns of innovation are interrelated, and how these interrelations can be explained. The intersectoral, 'systemic', aspects of technology shifts have been stressed in a variety of empirical and theoretical accounts (Dahmén, 1950; Rosenberg, 1969; Gille, 1978; Hughes, 1987; Carlsson & Stankiewicz, 1991; Nelson, 1994). The literature proposes that technological change takes place by way of strong mutual interdependencies between some industries, sometimes geographically localized, and that innovation activity is profoundly shaped by these interdependencies.

The current chapter contributes to the understanding of interdependencies between industries in the process of technological change. A key issue is to what extent the co-evolution of innovation and industries takes place by way of the mere exploitation of technological opportunities and downstream improvement of key inputs or rather by way of overcoming hurdles. Two main types of intersectoral mechanisms spurring innovation have been proposed. The concept of general purpose technologies suggests that broader technology shifts take place by the exploitation of technologies that have a general purpose character. Complementarities between supply industries and user industries emerge when user sectors improve and enhance the key input (Bresnahan & Trajtenberg, 1995). By contrast, other approaches have stressed that technology shifts evolve not only by the downstream improvement of new technologies, but by the solution of imbalances and techno-economic problems that appear (Hughes, 1983, 1987; Dahmén, 1950; Rosenberg, 1969; Dahmén, 1991a). More than the concept of general purpose technologies or other related ones, these approaches set focus on the inertia in the evolution of new technologies. The concept of "technological systems" - first used by Thomas Hughes (1983, 1987) - may be understood as a set of interacting and interdependent components in which technologies evolve by way of the solution of 'critical problems' (Hughes, 1987). The notion of "development blocks" is similar in essence. It may be understood as sequences of complementarities between firms and industries that emerge as firms resolve technological imbalances (Dahmén, 1950, 1991a). Such sequences of complementarities may be viewed from a macro-level, industry and even micro-level perspective, consisting of actor-networks, sets of industries or broader development blocks such as the sets of technologies formed around a general purpose technology.

The development block approach is well-suited for the current study since it may be understood on various levels of analysis. It is also well-suited as it stresses the role of imbalances, while acknowledging the role played by technological opportunities. The extent to which these factors may have influenced innovation activity remains an empirical question.

Previous studies employing the development block approach have predominantly reserved the term for the broader sets of complementary factors, connected to the three industrial revolutions. A contribution in this study is a more detailed picture of industry interdependencies in innovation activity and imbalances that have spurred innovation activity during the period studied.

6.1.1 Disposition and method of analysis

The main question of this chapter is to what extent and how innovation activity has been shaped by interdependencies between industries. This main question is answered by posing two sub-questions:

- *What industries were related in terms of innovation flows?*
- *To what extent and how has innovation activity responded to opportunities and technological imbalances in development blocks?*

In the current work a new method is proposed to shed light on interdependencies and development blocks by combining textual evidence on innovations that respond to technological imbalances, and a quantitative approach to delineate related industries, using recent contributions to network analysis.

The analysis is carried out in two steps. The first issue addressed is to measure and describe what industries have formed strong mutual linkages in terms of the supply and use of innovations over the period 1970-2007. This analysis results in a description of closely related industries. The second issue is to analyse the qualitative content of such interdependent industries. Previous research has employed a wide set of approaches to analyse and describe economic, knowledge and technological interdependencies in terms of subsystems. The classical analysis of economic interdependencies has departed from Input-Output matrices of economic flows or models of vertically integrated sectors (von Neumann, 1945; Leontief, 1941; Pasinetti, 1973, 1983). Leontief (1963) and Sraffa (1960) discussed the problem of finding subsystems in such economic flows. Leontief for instance proposed a block partition of non-zero elements in the Input-Output framework. Interdependencies between industries could be analysed as the "dynamic inverse" in the Input-Output framework (see e.g. Goodwin, 1949).

Similar in aim to the current study, Enflo et al. (2008) employed cointegration analysis between industrial production volumes in Sweden (1900 - 1970) to approach interdependencies between industries and sets of closely related sectors, indicating development blocks. Studies in economic geography have measured industry relatedness by measuring the coproduction of different products on the plant-level (Neffke & Svensson Henning, 2008; Neffke et al., 2011). Mappings of the patterns of production and use of inventions or innovations have been constructed since the 1980s (see Los & Verspagen, 2002 for an overview), employing patent data (Scherer, 1982; Verspagen, 1997; van Meijl, 1997; Nomaler & Verspagen, 2008, 2012) and innovation output data (DeBresson & Townsend, 1978; Robson et al., 1988; DeBresson et al., 1996). The so-called technology flow matrices constructed with patent data have in general been used to measure the intersectoral spillover effects of knowledge. Robson et al. (1988) used a matrix of the number of innovations produced and used in industries, to draw conclusions about the location of innovative activity in Great Britain. These studies were for instance underlying Pavitt's 1984 seminal study and taxonomy of innovation. Recent research (McNerney et al., 2013; Garbellini & Wirkierman, 2014) has suggested that subsystems in economic flows may be analysed by way of network analysis and the detection of *communities*. This analysis can be extended to the case of innovation flows. A *community* is then a set of industries that form close connections in terms of the flow of innovations.

In this work, the overall interdependencies and flows of innovations between industries are studied by mapping the number of innovations in a product group to the respective sectors of use. The resulting "Object Matrix" (Archibugi & Simonetti, 1998), informs us of in what sectors innovations were produced and used, and may be considered a measure of the linkages between product groups and sectors of economic activity. The raw statistics of the Innovation Flow Matrix can be used to describe what sectors were salient sectors of supply and use of innovations, and how these patterns have changed during the period 1970-2007. An analysis of related industries can be carried out in a statistical approach using network analysis and community detection.

Communities are thus statistical descriptions of closely related industries. These industries may be said to reflect *development blocks* if innovations create complementarities within the communities, or if innovations are "gap filling", i.e. respond to technological imbalances by supplying missing components or factors in a relation of complementarity. Thus communities indicate development blocks *if* the qualitative character of interdependencies can be assessed as creating complementarities or supplying complementarities by solving imbalances.

Fortunately, the SWINNO database gives a rare opportunity to jointly study two central facets of technology shifts: the response to technological imbalances, and innovation as the response to and downstream improvement of technological opportunities. The second aim is therefore to describe and analyse how innovation activity has been spurred by opportunities and problems arising in industries, that which has been called "technological imbalances".

Thus, the statistical analysis of interdependencies in 'communities', may be qualified by an analysis of the creative response to technological imbalances and technological opportunities. By combining the analysis of subgroups of industries and the analysis by problem-solving innovations, groups of industries linked by problem-solving innovations can thus be related to Dahmén's concept of development blocks: sets of complementarities that appear sequentially as economic agents solve technological imbalances.

Table 6.1: Schematic picture of flows of innovation.

	User Industry 1	2	...	N	Final Consumption	General Purpose
Supply Industry 1	W_{11}	W_{12}	...	W_{1N}	$W_{1,FC}$	$W_{1,GP}$
2	W_{21}	W_{22}	...	W_{2N}	$W_{1,FC}$	$W_{2,GP}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
N	W_{N1}	W_{N2}	...	W_{NN}	$W_{N,FC}$	$W_{N,GP}$

Note: W_{ij} maps innovations supplied from industry i to j, $W_{i,FC}$ innovations in industry i used for final consumption, and $W_{i,GP}$ innovations for general purposes.

6.2 Patterns of production and use of innovations

6.2.1 The construction of the Innovation Flow Matrix

To analyse the supply and use of innovations it is necessary to employ variables on the supply industry and user industry of innovations. The product innovations found in the journal articles were categorized in the Swedish Industrial Classification system 2002 (SNI 2002) corresponding to ISIC Rev 2. The variable "User" describes the sectors (SNI 2002) in which the innovation is used or explicitly intended to be used according to the trade journal articles. An innovation is allowed in the database to have up to eight different user sectors. The User sectors were classified at the lowest industry-level possible. The level of classification thus may vary. Whereas most User sectors are specified on a three or four digit SNI level, some innovations are directed towards broader sectors corresponding better to two digit SNI levels.

Apart from the given user industries two auxiliary categories have been registered: final consumers and general purpose. The former category refers to innovations for private use. The latter category refers to innovations for use in almost any sector (frequently including final consumption).

The innovation flow matrix is an analytical tool that allows one to picture and analyse the supply and use of innovations and the linkages between industries. It is constructed by mapping the innovations developed in industry i that are used in sector j, final consumption, or are of general purpose character, illustrated by the Table 6.1.

In the simplest case, the matrix could be constructed by counting the number of innovations of type i that are directed towards user sector j. We then obtain a matrix, mapping the number of times an innovation in the database is found to be of product group i and used in sector j.

An innovation may however have several user sectors. Depending on the purpose of analysis one may either count all observed linkages between sectors or counting each innovation only once by applying a weighting procedure. In the first case an innovation with two user sectors is counted as two observations. This method gives a relatively large weight to innovations that are used in many different sectors. The first method could be preferred if the study aims to analyse the economic impact or diffusion of innovations in the economy.

By contrast, the second method implies that the more user sectors an innovation has, the *weaker* the linkage between two specific sectors of supply and use. If an innovation has two different user sectors, each of these linkages is given a weight of 1/2, ascertaining a total sum of 1. The second method is suitable for studying the strength of technological linkages between certain sectors, which is the purpose of the analysis in this chapter. Though not essential for the current analysis, the second method is also consistent with a probabilistic treatment of the flow of innovations, as the calculation of the probability that an innovation is used in a certain sector is straightforward.[1]

Following the second method, each linkage between a supply and a user sector is thus weighted by the inverse of the innovation's total number of observed user sectors. The second innovation flow matrix W is constructed by taking the sum of all weighted linkages between industry i and industry j. The elements W_{ij} of the matrix are thus weighted sums and will not be integers. However, since each innovation is only counted once, the row sums W_i will be equal to the count of innovations supplied.[2] In what follows, all following statistics on the supply and use of innovations refer to weighted sums calculated according to this method.

The treatment of general purpose innovations is an exception from the

[1] This e.g. makes possible the analysis of the IFM matrix as a stochastic Markov process where the matrix $W_{ij}/\sum_j(W_{ij})$ is the transition matrix. Compare e.g. DeBresson & Hu (1996).

[2] Formally, given a set of N innovations indexed by $k \in \{1, 2, ..., N\}$, each innovation has a number of observed user industries U. The weight w for a linkage of innovation k is then $w_k = (1/U_k)$. Assigning each weight to its respective supply and user industry, i and j respectively, we obtain the innovation flow matrix W with elements $W_{ij} = \sum_k(w_{ijk})$.

weighting procedure that merits explanation. General purpose innovations could in principle be counted by giving a (small) weight to each user industry (e.g. signifying a small probability that the innovation would be used in a certain industry). However, as it is far from obvious how general purpose innovations should be weighted, general purpose innovations have been retained as a separate category. Innovations that are recorded as general purpose innovations are thus counted separately and do not enter the weighting procedure.

6.2.1.1 Limitations

The study of interdependencies across industries is naturally limited by the scope of the data used. The study of supply of innovations is limited to software innovations and innovations developed in the manufacturing industry. This implies the role of the supply of certain service innovations for manufacturing industries is not accounted for. However, it is possible to study the use of innovations across the board. Thus the role of product innovations in manufacturing industries for other manufacturing industries and the economy as a whole can be assessed. This chapter thus primarily studies interdependencies between manufacturing industries and their user sectors.

6.2.2 Patterns of use of innovation 1970-2007.

In this section the main patterns of use of innovations are summarized. In Table 6.2 the counts of innovations are shown distributed by their user sectors, including the categories final consumption and general purpose innovations. This introduces the structure of the flow of innovations in a broader perspective.

For 4040 commercialized innovations a user industry could be recorded. Throughout the period a majority (67.94%) of the innovations have been aimed to be used in the production of goods or services. 943 (23.34%) innovations were recorded as general purpose innovations. The weighted sum of innovations for final consumption constituted 8.72% of the total count of innovations during the period.

It is perhaps unexpected to find stable shares of innovations for use in the manufacturing and service sectors, given the widely acknowledged transformation towards a service economy (Table 6.2). Innovations for use in manufacturing purposes corresponded in total to roughly a third of the total count, throughout the period (36.5% in 1970-1989, 38.48% in 1990-2007). Innovations for use in services (SNI 50-93) corresponded in total to 18.66% during the period. Electricity, gas and water supply (SNI 40-41) and Construction (SNI 45) corresponded to small shares (1.9% and 6.08% respectively).

Table 6.3 breaks down the user industries within the manufacturing sector on a 2 digit level. In the first half of the period 1970-1989, the principal manufacturing user industries were foodstuff (SNI 150), fabricated metal products (SNI 280), and manufacturing of machinery and equipment (SNI 290). The principal service users (see Table 6.2) were transportation and storage services (SNI 600-630), and health care services (SNI 850). During the period studied a shift of user industries however did take place. Whereas the shares of manufacturing and service were stable, the importance within manufacturing and within service industries changed.

The change in users of innovation can be described as a shift from the above-mentioned user industries within the traditional industry (e.g. SNI 150, 280 and 290) and transportation services (SNI 600-630), towards five groups of industries: production of motor vehicles (SNI 340), the ICT sectors (SNI 30-32 and 72), Electricity (40), health care services (SNI 850) and other business services (R&D and consultancy, SNI 730-740). These patterns can be seen in Tables 6.2 and 6.3 and are shown in Figures 6.1 and 6.2. The seven largest user industries with increasing shares in the total count of innovations are displayed in Figure 6.1. The relative increase of these seven user industries is connected to the increased supply of automotive, medical and biotechology and ICT innovations.

In Figure 6.2 the ten most important user industries with negative trend are displayed. These are all traditional industries, most of which can be labelled stagnating or receding. Despite a negative trend, the decrease is however not radical in most cases. Together the ten most important user industries made up 23.84% in 1990-2007. This indicates that traditional industries were still important users of innovation.

6.2.2.1 General purpose innovations and final consumption

In chapter 4, it was argued that there was a shift among ICT innovations during the period studied. During the first half of the period there was a broad development block centered on factory automation and industrial use. In 1990-2007 however the development was spearheaded by telecommunications and software, ultimately oriented towards final customers. This can

Table 6.2: Distribution of innovations (weighted), by user industries in total economy.

Sectors (SNI)	1970-1989	%	1990-2007	%	1970-2007	%
Agriculture and Fishing (01-05)	84.83	3.66	21.26	1.27	106.1	2.63
Mining (10-14)	53.65	2.32	21.31	1.28	74.96	1.86
Manufacturing (15-37)	845.66	36.5	642.31	38.48	1487.97	36.83
Electricity, gas and water supply (40-41)	40.62	1.75	36	2.16	76.62	1.9
Construction (45)	169.84	7.33	75.61	4.53	245.45	6.08
Wholesale trade (50-54)	24.58	1.06	15.42	0.92	40	0.99
Hotel and restaurants (55)	15.12	0.65	2.14	0.13	17.26	0.43
Transportation and storage (60)	147.78	6.38	61.38	3.68	209.17	5.18
Communications (64)	5	0.22	19.17	1.15	24.17	0.6
Financial (65-67)	5.7	0.25	4.25	0.25	9.95	0.25
Other business activities (70-74)	52.32	2.26	66.79	4	119.11	2.95
Public administration and defence (75)	42.7	1.84	55.2	3.31	97.9	2.42
Education (80)	3.5	0.15	2.33	0.14	5.83	0.14
Health care (85)	76.17	3.29	79.04	4.74	155.21	3.84
Final consumption	135.25	5.84	217.12	13.01	352.37	8.72
Other societal and social services (90-93)	52.28	2.26	22.67	1.36	74.95	1.86
General purpose	562	24.26	381	22.83	943	23.34
Total	2317	100	1723	100	4040	100

Table 6.3: Distribution of innovations (weighted) by user industries in manufacturing (two digit SNI).

	1970 - 1989	%[a]	1990 - 2007	%[a]	1970 - 2007	%[a]
Food products and beverages (15)	104.1	4.49	53.34	3.1	157.44	3.9
Tobacco (16)	0.25	0.01	0	0	0.25	0.01
Textiles, wearing apparel and leather (170-190)	31.83	1.37	10.08	0.59	41.92	1.04
Wood and of products of wood and cork (20)	66.66	2.88	43.96	2.55	110.62	2.74
Pulp, paper and paper products (21)	73.73	3.18	60.54	3.51	134.26	3.32
Publishing, printing and reproduction of recorded media (22)	59.7	2.58	42.08	2.44	101.78	2.52
Coke, refined petroleum products and nuclear fuel (23)	3.14	0.14	3.66	0.21	6.8	0.17
Chemicals and chemical products (24)	59.44	2.57	31.07	1.8	90.5	2.24
Rubber and plastic products (25)	42.05	1.81	14.47	0.84	56.52	1.4
Other non-metallic mineral products (26)	11.3	0.49	0.71	0.04	12.01	0.3
Basic metals (27)	61.94	2.67	25.38	1.47	87.32	2.16
Fabricated metal products (28)	96.44	4.16	41.98	2.44	138.41	3.43
Machinery and equipment n.e.c. (29)	76.88	3.32	42.31	2.46	119.19	2.95
Office machinery and computers (30)	9.72	0.42	7.03	0.41	16.75	0.41
Electrical machinery and apparatus n.e.c. (31)	13.15	0.57	10.21	0.59	23.35	0.58
Radio, television and communication equipment and apparatus (32)	34.83	1.5	41.24	2.39	76.07	1.88
Medical, precision and optical instruments, watches and clocks (33)	7.36	0.32	18.74	1.09	26.1	0.65
Motor vehicles, trailers and semi-trailers (34)	71.55	3.09	113.99	6.62	185.55	4.59
Other transport equipment (35)	36.05	1.56	36.56	2.12	72.61	1.8
Furniture; manufacturing n.e.c. (36)	12.06	0.52	12.18	0.71	24.24	0.6
Recycling (37)	4.25	0.18	2	0.12	6.25	0.15
Total Manufacturing	876.43	37.83	611.53	35.49	1487.94	36.83
Total Economy	2317	100	1723	100	4040	100

[a] Calculated as the sum of innovations (weighted) in user industry j divided by the total count of innovations in the total economy.

Figure 6.1: Seven largest user industries with increasing shares. Share of innovations in total count (%).

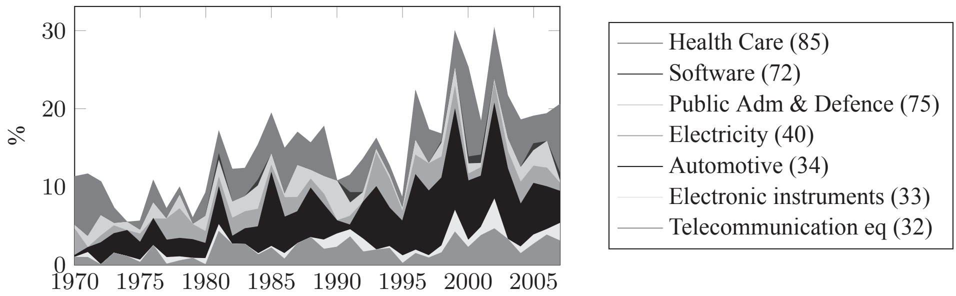


Figure 6.2: Ten largest user industries with decreasing shares over time. Share of innovations in total count (%).

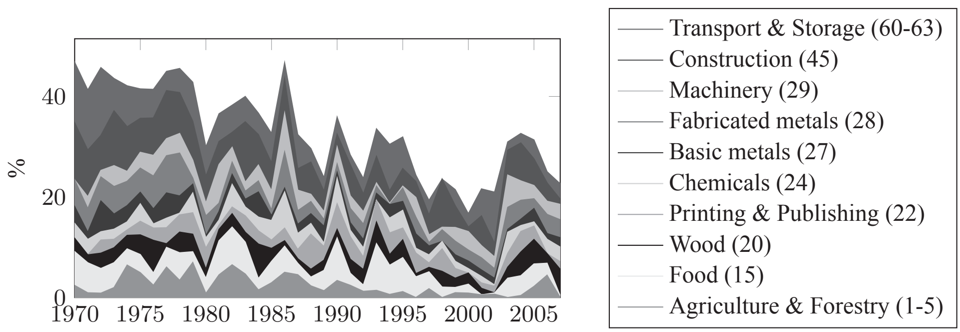
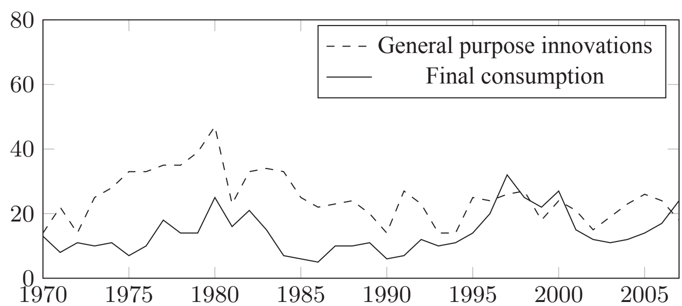


Figure 6.3: Innovations for general purpose use or use in final consumption (absolute counts).



also be observed in the current results. In Figure 6.3 the count of innovations for final consumption and general purpose of innovations are shown. During the period innovations for final consumption were markedly increasing during the 1990s, concomitant with the increase in the supply of telecommunication equipment innovations (SNI 322 and 323) and final customer oriented software innovations.

The count of general purpose innovations were rather constant throughout the period. 407 out of 891 general use innovations were hardware electronic equipment (SNI 30-33). The claim that ICT-innovations have been of general purpose character thus obtains support from these results.

6.3 The supply and use of innovations

This section describes and summarizes the main patterns of supply and use of innovations across industries.

In the previous section it was found that there has been a shift from traditional sectors to the ICT industries in the user industries, similar in character to the shift in the supply of innovation. In Tables 6.4 and 6.5 the supply and use of innovations is presented at the aggregated level. Table 6.4 shows that for most supply industries the larger part of innovations were used in other manufacturing industries. Exceptions were wood and wood products (DD, i.e. SNI 20) and other metallic mineral products (DI, i.e. SNI 26) that found used in construction, and chemicals and chemical products (DG, SNI 24) that found use in health care. In Table 6.5 stronger linkages between manufacturing industries are highlighted. The table allows a broad comparison between the main types of innovation, basic metals and fabricated metal products (SNI 27-28), machinery (29) and hardware ICT products (SNI 30-33). The main user industries of ICT products were health care (SNI 85), other business activities (SNI 70-74) and aimed for internal use or other parts of the hardware ICT sector (SNI 30-33). By contrast, the principal user industries of machinery innovations were traditional manufacturing industries, e.g. the pulp & paper and printing industries (SNI 21-22), fabricated metal products and basic metals (SNI 27-28), foodstuff (SNI 15-16), and the construction (SNI 45) and agriculture and forestry sectors (SNI 1-5). User industries of basic metals and fabricated metal innovations were construction (SNI 45), transport equipment (SNI 34-35). A large portion were aimed for internal use or other parts of the metals sector.

Table 6.4: Aggregated Innovation Flow Matrix, Total economy, 1970 - 2007.

Sector	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	FC	GP	Total supply
A	1.5	0	0.33	0.66	0	0	0	0.5	0	0	0	0	0	0	0	0	0	3
C	1.5	0	0	2	0	0	0	0	0	0	0	0	0	0	0.5	1	0	5
DA	1	0	0	13	0	0	1.5	8.83	1	0	0.33	0	0	0	0	43.33	1	70
DB - DC	1.5	1	0	9	0	2	0	0	0	0	0.5	2	0	1	2	5	3	27
DD	1	0	0	13	1	33	0	0	1.5	0	0	0	0	0	1	6.5	8	65
DE	1	0	0	33.99	1	5	1.5	0	3	0	0	0	0	0	0	4.5	12	62
DF	0	0	0	1	3	2	0	0	0	0	0	0	0	0	0	1	1	8
DG	8	0	2	56.51	0.5	9.7	1	0	2	0	3	0	0	39.75	7.5	11.03	16	157
DH	4.5	1	2.83	90.66	3	22.33	3.08	0	14.17	0	1.25	7	0	3	2	14.17	19	188
DI	0	0	0	12	0	17.25	0	0	0.25	0	0	1	0	0	0	1.5	3	35
DJ	2.5	1	10.73	162.21	7.5	44.49	0.33	2	17.2	1	0.7	4.5	0	3	1.5	20.33	38	317
DK	61	2	35.4	527.9	19.58	59.03	14.43	3.25	51	1	9.85	21.7	1.83	9.33	31.28	57.42	248	1154
DL	6.93	1	13.96	358.25	33.53	23.81	12.82	2.68	72.85	5.45	71.23	29.87	2	88.13	12	132.5	407	1274
DM	4.17	1	4.5	83.71	1	5.33	1.33	0	56.2	0	3.33	26.33	0	2	5.33	15.75	19	229
DN	0.5	0	0	10.5	0	2	0	0	0	0	0	1	0	0	0.5	8.5	17	40
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
F	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	1	7
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
I	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4	7	14
J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
K	4	0	5.7	119.04	6.5	13.5	4	0	11.17	3	29.92	5	2	9	11.33	22.83	90	337
N	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
Total use	99.1	7	75.46	1493.48	76.62	245.45	40	17.26	233.33	10.45	120.11	98.4	5.83	156.21	74.95	353.37	891	3998

A = Agriculture, hunting and forestry, B = Fishing, C =Mining and quarrying, DA = Food products; beverages and tobacco, DB = Textiles and textile products, DC = Leather and leather products, DD = Wood and wood products, DE = Pulp, paper and paper products; publishing and printing, DF = Coke, refined petroleum products and nuclear fuel, DG = Chemicals, chemical products and man-made fibres, DH = Rubber and plastic products, DI = Other non-metallic mineral products, DJ = Basic metals and fabricated metal products, DK = Machinery and equipment n.e.c., DL = Electrical and optical equipment, DM = Transport equipment, DN = Manufacturing n.e.c., E = Electricity, gas and water supply, F = Construction, G = Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, H = Hotels and restaurants, I = Transport, storage and communication, J = Financial intermediation, K = Real estate, renting and business activities, L = Public administration and defence; compulsory social security, M = Education, N = Health and social security, O = Other community, social and personal service activities, FC = Final consumption, GP = General purpose

Table 6.5: Innovation flow matrix of innovations used in manufacturing industries, 1970-2007.

Sector	DA	DB-DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	Total supply 15-37	Total supply
A	0	0.33	0	0.33	0	0	0	0	0	0	0	0	0	0.66	3
C	0	0	0	0	0	0	0	0	2	0	0	0	0	2	5
DA	10	0	1	0	0	1	0	0	0.5	0.5	0	0	0	13	70
DB-DC	0	3	0	2.5	0	1.5	0.5	0	0	0.5	0	0	1	9	27
DD	0.5	1	6.5	0	0	0	0.33	0	0	0	0	0	4.67	13	65
DE	9.5	0	3.33	14.33	0	1	1.83	0	1.17	1.33	0	1.5	0	33.99	62
DF	0	0	0	0	0	0	1	0	0	0	0	0	0	1	8
DG	3	3.25	4	9.83	0	7	6.33	0	5.33	1.12	8.05	5.57	3.03	56.51	157
DH	36.08	0.83	4	2.75	0	4.08	5.17	3.33	3.14	11.23	1.93	16.29	1.83	90.66	188
DI	0	0	0	0	0	0.5	0.5	2	3.75	1.75	0	3.5	0	12	35
DJ	9	1.5	11.08	2.75	0	2	4	1	51.1	28.77	12.88	32.54	5.59	162.21	317
DK	63.32	29.17	49.3	104.09	1.92	35.77	21.72	3.26	89.44	38.77	19.83	60.11	11.2	527.9	1154
DL	22.09	1.83	25.57	63.34	4.64	28.12	6.1	1.55	49.39	20.47	84.74	50.41	0	358.25	1274
DM	0.7	0	1.83	0.58	0.25	0.2	0.5	0	1	3.67	0.4	74.58	0	83.71	229
DN	0	0	0	3	0	0	0	0	5.5	1	0	1	0	10.5	40
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
K	3.5	1	4	34.53	0	9.83	8.53	1.2	13.74	11.43	14.45	13.33	3.5	119.04	337
N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Total use	157.69	41.92	110.62	238.05	6.8	91	56.52	12.35	226.07	120.52	142.28	258.83	30.83	1493.48	3998

A = Agriculture, hunting and forestry, B = Fishing, C =Mining and quarrying, DA = Food products; beverages and tobacco, DB = Textiles and textile products, DC = Leather and leather products, DD = Wood and wood products, DE = Pulp, paper and paper products; publishing and printing, DF = Coke, refined petroleum products and nuclear fuel, DG = Chemicals, chemical products and man-made fibres, DH = Rubber and plastic products, DI = Other non-metallic mineral products, DJ = Basic metals and fabricated metal products, DK = Machinery and equipment n.e.c., DL = Electrical and optical equipment, DM = Transport equipment, DN = Manufacturing n.e.c., E = Electricity, gas and water supply, F = Construction, G = Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, H = Hotels and restaurants, I = Transport, storage and communication, J = Financial intermediation, K = Real estate, renting and business activities, L = Public administration and defence; compulsory social security, M = Education, N = Health and social security, O = Other community, social and personal service activities

6.3.1 Network analysis of intersectoral patterns of innovation

In the previous section the Innovation Flow Matrix has been presented at a fairly aggregated level. The full detail Innovation Flow Matrix however is a 103×103 matrix, with 10 609 possible entries. A detailed description of the flow of innovations requires the use of more complex descriptive statistics due to the complexity and size of the data.

Using network analysis, patterns of supply and use of innovation can be described in terms of industries which are *related*, or to be precise: industries that have more innovation interactions between each other than to other industries. The goal of the present analysis is to describe the main flows of innovations in terms of related industries. The results are used in subsequent sections to analyse how interdependencies between industries have shaped innovation activity.

The main vehicle of analysis is network analysis and community detection. A network, or graph, consists of a set of vertices (also called nodes), which are connected by edges (also called lines). Networks can be of different types. In unweighted networks the occurrence of a connection between edges counts. In weighted networks, the number of connections between edges matter, or the connections are assigned different weights. Many networks are undirected, which implies that connections are mutual. Networks may however also be directed, in which case it is possible that an edge i has a relation with another edge j, but not vice versa. The Innovation Flow Matrix can basically be understood as a weighted, directed network, meaning that both the count of innovations and the direction of the connections between industries matter.

Graphs may to a greater or lesser extent be possible to subdivide into subgroups, called communities. In a graph, in which all nodes are connected there is a weak community structure. In a graph in which some nodes are connected but not to all other nodes, there is a stronger community structure.

Recent developments in network theory make it possible to find subgroups within a system of economic or technology flows (see Fortunato 2010; Malliaros & Vazirgiannis 2013 for reviews of community detection approaches in directed networks and Garbellini 2012 for an overview of methods applicable to economic input-output data).

There are many approaches to divide social, technological or other networks into subgroups. The approach employed here is based on the concept of modularity, which is a descriptive statistic designed to measure the strength of division of a network into communities. The modularity of a network Q is defined as the sum of share of edges that fall into communities minus the expected shares of such edges:

$$\begin{aligned} Q = &\text{(share of edges within communities)} \\ -&\text{(expected share of edges within communities)} \end{aligned} \tag{6.1}$$

Formally, in our directed innovation network W_{ij}, the modularity is calculated as

$$Q^{dir} = \sum_{ij} \left(\frac{W_{ij}}{k} - \frac{k_i^{out} k_j^{in}}{k^2} \right) \delta_{c_i c_j} \tag{6.2}$$

$\frac{W_{ij}}{k}$ is the actual shares of flows between industry i and j, where k is the sum total of flows in the network. The expected shares of flows from industry i to j is calculated as the product of the share of innovations supplied by i, k_i^{out}/k, and the share of innovations used by j, k_j^{in}/k. The expected share of innovations assuming a random distribution is $\frac{k_i^{out} k_j^{in}}{k^2}$. $\delta_{c_i c_j}$ (the so-called Kronecker delta) assumes values 1 if $c_i = c_j$ i.e. if i and j belong to the same community, and 0 otherwise.

The value of modularity lies between -1 and 1, being positive if the number of edges or weights within groups exceeds the number of edges or weights expected. Modularity approaches 1 when no edges flow between communities and all edges flow within communities. Conversely, modularity approaches -1 when no edges flow within communities but only between communities. According to Clauset et al. (2004, p. 2) "in practice it is found that a value above about 0.3 is a good indicator of significant community structure in a network."

The problem of finding a community division that maximizes modularity is technically non-trivial. While attaining the same end-goal, there are several algorithms proposed to solve the problem, each with merits and limitations. Since there is no algorithm that finds the community division that maximizes modularity *a priori*, the results section compares three similar community detection algorithms that are suitable for weighted networks. Newman (2004) proposed an efficient "greedy search" algorithm, in which vertices are joined into the same groups if they achieve the largest increase in modularity. Here the improved algorithm by Clauset et al. (2004) is used. The algorithm proposed by Clauset et al. (2004) is efficient and widely used but limited to undirected weighted networks. Thus, only the total count of innovations flowing between two industries are taken into account, but not the direction of the flows.

A spectral bisection algorithm for detection of community structures in weighted *directed* networks was suggested by Leicht & Newman (2008), generalizing the suggestions of Newman (2006) to directed networks. The task of the algorithm is to yield a subset of vertices which maximize the modularity, by way of a process of repeated bisection (i.e. subdivision into two partitions). The algorithm arrives at communities which are further indivisible, i.e. any further division into new communities does not improve modularity.[3]

The first algorithm was applied using the igraph package (see Csardi & Nepusz, 2006) in software environment R. The two latter algorithms for weighted undirected and directed graphs were executed by the author in software environment R, following Leicht & Newman (2008) and the fine tuning algorithm described in Newman (2006). The steps of the two latter algorithms are described in Appendix B. The results are presented in the next section.

6.3.2 Results

During the period studied there are stable patterns in the supply and use of innovations. The results are summarized in Tables 6.6, 6.7 and 6.8. The results first of all indicate the existence of a strong community structure. With all three methods, the network partitions result in a modularity above 0.3, which indicates a significant community structure.[4] The highest modularity is yielded by the fast greedy algorithm (Clauset et al., 2004), suggesting ten communities in the Innovation Flow Matrix for the period 1970-2007. The other two algorithms suggest ten and eleven communities but have slightly lower modularity. The importance of the proposed community structure is assessed by the modularity statistic. The modularity of the community is

[3] A drawback with the modularity approach in general is however, that the communities are not allowed to be overlapping, i.e. a sector of product innovations is only allowed to belong to one community. Nicosia et al. (2009) have considered an extension of the approach proposed by Leicht & Newman (2008) but at this date there is no algorithm that allows for the identification of overlapping subgraphs that maximize the modularity of a given graph.

[4] To recapture: The modularity ranges between -1 and 1. If modularity is positive the weights within communities are larger than the expected values of weights were generated by a random process. According to Clauset et al. (2004) a modularity above 0.3 indicates a significant community structure.

Table 6.6: Summary statistics of partitions for IFM 1970-2007.

	Fast greedy	Leading eigenvector (undirected)	Leading eigenvector (directed)
Modularity	0.3430	0.3067	0.3424
N. communities	10	10	11
NMI fast greedy	1	0.6440	0.7672
NMI leading eigenvector(undirected)	0.6440	1	0.6713
NMI leading eigenvector (directed)	0.7672	0.6713	1

Normalized mutual information (NMI) compares the similarity between the partitions of networks into communities.

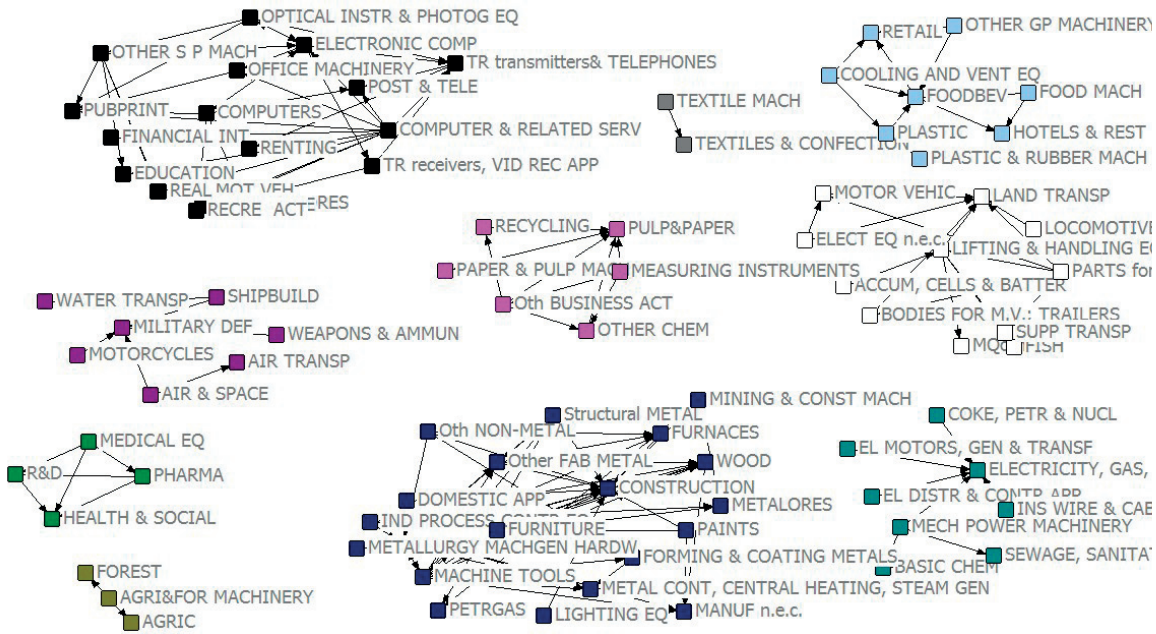
0.34 for the whole period. The innovations flowing within the communities found capture 45% of the total count of innovations. Moreover, the results from the three different community detection algorithms are similar. An indication of the robustness of the partitions may be obtained by calculating the NMI (Normalized Mutual Information), which compares the similarity between the proposed partitions (Danon et al., 2005). The similarity between partitions is reported in Table 6.6. The statistic ranges between 0, if the partitions are disjunct, and 1, if the partitions are identical. The lowest found NMI is 0.6440, whereas the NMI between the partition suggested by the fast greedy and leading eigenvector algorithm for directed networks is 0.7672.[5]

While the results are similar, the fast greedy algorithm finds the best partition.[6] The communities suggested are described in Tables 6.7 and 6.8, where they have been labelled according to the most significant sector of supply or use.

[5]Following Danon et al. (2005) the normalized mutual information (NMI) is calculated as $\frac{-2\sum_{ij} N_{ij} ln(N_i j N / N_i N_j)}{\sum_i (N_i ln(N_i/N)) + \sum_j (N_j ln(N_j/N))}$, where N_{ij} is the number of nodes found in community i of the first partition and community j of the second partition.

[6]This decision is based upon the modularity statistic only. The second best alternative suggested by the leading eigenvector algorithm for the directed network differs in one notable aspect. It distinguishes a separate block of innovations focused on transport and storage (SNI 630) and lifting and handling equipment (SNI 29220). In the best partition, these industries are contained within the community centered on automotive vehicles and land transportation (see Table 6.7 and 6.8).

Figure 6.4: Communities suggested by fast greedy algorithm.



The communities are from the upper left: ICT innovations (black), Textiles and clothing (gray), Food products and packaging (light blue), Shipbuilding, aircraft and military defence (lilac), Pulp and paper (pink), Automotive vehicles and land transportation (white), Medical (green), Forestry (brown), Construction, metals and wood (dark blue), Electricity (turquoise)

The communities are depicted as networks in Figure 6.4, which highlights flows of innovations within the communities. Clearly, some communities encompass a large number of industries, while some consist of a smaller number of industries. The revealed community structure is to a surprisingly large extent consistent with previous research on Swedish innovation activity and previous descriptions of important interindustry linkages and interdependencies. Two of the communities correspond to the ICT and the biotechnology innovations described in chapter 4. Community 3 in Tables 6.7 and 6.8 consists of all ICT industries. It can be understood as composed by three components. As discussed in chapter 4, ICT innovations were developed for use in electronic components (SNI 321) and telecommunication services (SNI 640) during the second half of the period. These innovations were strongly connected to the deployment of Internet and telecommunications. During the first half of the period a development block surrounding factory automation was expanding, consisting of computer innovations (30020), control systems (333) and electronic components (321) (Carlsson, 1995). The community also reveals that, during this period, a large share of computer innovations (SNI 30020), among with office equipment (SNI 30010) was aimed for applications in publishing and printing (SNI 220).

Community 5 spans medical equipment innovations, pharmaceuticals, health care and the research and development sector. This community corresponds well to what has been referred to as the medical and biotechnology "cluster" or "technological system" in chapter 4 and in previous research (Stankiewicz, 1997; Backlund, Häggblad, et al., 2000). As discussed in chapter 4 however, biotechnology innovations also include parts of the foodstuff and agricultural innovations.

A broad and important community of innovations (Community 7 in Table 6.7 and 6.8) was formed around the construction and mining sectors and materials for construction purposes, e.g. wood products, metals and fabricated metals, rubber and other non-metallic mineral products. This community also involves machinery for construction and mining, machine-tools and machinery for the processing of wood products and metals.

The remaining communities found were made up of supply industries more or less concentrated to one or two specific user industries: the pulp and paper industry (Community 1), food products (Community 2), automotive vehicles and land transportation (Community 4), Forestry (Community 6), Shipbuilding and Military defence (Community 8), Electricity production and distribution (Community 9) and Textiles and clothing (Community 10).

Table 6.7: Description and summary statistics of communities suggested by the fast greedy algorithm for IFM 1970-2007.

Brief description of community	Sum of weights within	Count of innovations involved[a]	Total count of innovations involved (including GP and FC)[b]
Pulp and paper	134.82	187	324
Food products and packaging	129.81	151	303
ICT innovations	219.04	268	715
Automotive vehicles and land transportation	155.56	202	329
Medical	120.11	128	135
Forestry	47.67	50	55
Construction, metals and wood	404.88	451	642
Shipbuilding, aircraft and military defense	50.34	57	69
Electricity	48.61	82	172
Textiles and clothing	30.69	34	44
SUM	1341.51	1610	2788
Total IFM[c]	2743.63	3998	3998

[a] Count of innovations for which there is at least one linkage within the respective communities.

[b] Total count of innovations for which there is at least one linkage within the respective communities, including innovations for general purpose and final consumption.

[c] In the first row, the total refers to the total sum of weights in the IFM 1970-2007, when innovation for general purpose and final consumption are excluded. In the second and third column these are included for comparison with the count of innovations involved in communities.

Table 6.8: Industry roles within the communities found for the IFM 1970-2007. Share of total number of innovations supplied or used within community.

Community	Main Suppliers (share of innovations supplied within community)	Main User (share of innovations used within community)
1. Pulp and paper	Instruments and appliances for measuring, checking, testing, navigating and other (SNI 332) 42.41%; Machinery for paper and paperboard production (SNI 29550) 28.56%; Other business activities (SNI 740) 18.94%	Pulp, paper and paper products (SNI 210) 65.55%; Other business activities (SNI 740) 22.28%
2. Food products	Plastic products (SNI 252) 30.33%; Machinery for food, beverage and tobacco processing (SNI 29530) 20.65%; Food products and beverages (SNI 150) 15.66%; Other general purpose machinery n.e.c. (SNI 29240) 14.6%; Non-domestic cooling and ventilation equipment (SNI 29230) 13.24%	Food products and beverages (SNI 150) 74.32%; Plastic products (SNI 252) 8.73%; Hotels and restaurants (SNI 550) 8.47%
3. ICT innovations	Other special purpose machinery n.e.c. (SNI 29569) 22%; Computer and related activities (SNI 720) 20.86%; Electronic valves and tubes and other electronic components (SNI 321) 12.55%; Computers (SNI 30020) 10.79%; Optical instruments and photographic equipment (SNI 334) 10.76%; Television and radio transmitters and apparatus for line telephony and line (SNI 322) 9.95%	Publishing, printing and reproduction of recorded media (SNI 220) 35.08%; Electronic valves and tubes and other electronic components (SNI 321) 10.38%; Post and telecommunications (SNI 640) 9.51%; Television and radio transmitters and apparatus for line telephony and line (SNI 322) 8.78%
4. Automotive vehicles and land transportation	Parts and accessories for motor vehicles and their engines (SNI 343) 38.14%; Motor vehicles (SNI 341) 19.99%; Lifting and handling equipment (SNI 29220) 16.94%; Electrical equipment n.e.c. (SNI 316) 11.89%	Motor vehicles (SNI 341) 48.77%; Land transport; transport via pipelines (SNI 600) 31.29%
5. Medical	Medical and surgical equipment and orthopaedic appliances (SNI 331) 62%; Pharmaceuticals (SNI 244) 34.55%	Health and social work (SNI 850) 87.42%
6. Forestry	Agricultural and forestry machinery (SNI 293) 94.76%	Forestry (SNI 20) 76.22%; Agriculture and hunting (SNI 10) 23.78%

7. Construction, metals and wood	Machine-tools (SNI 294) 22,25%; Basic metals (SNI 270) 13.16%; Wood and wood products, except furniture (SNI 200) 10.91%; Machinery for mining, quarrying and construction (SNI 29520) 9.49%; Cutlery, tools and general hardware (SNI 286) 7.02%	Construction (SNI 450) 36.65%; Wood and wood products, except furniture (SNI 200) 11.77%; Basic metals (SNI 270) 10.08%;
8. Shipbuilding, aircraft and military defense	Building and repairing of ships and boats (SNI 351) 54.49%; Weapons and ammunition (SNI 296) 21.14%; Aircraft and spacecraft (SNI 353) 21.06%	Provision of services to the community as a whole (SNI 752) 63.23%; Water transport (SNI 610) 21.52%
9. Electricity	Machinery for the production and use of mechanical power, except aircraft (SNI 291) 43.13%; Electricity distribution and control apparatus (SNI 312) 21.6%; Electric motors, generators and transformers (SNI 311) 13.42%; Basic chemicals, pesticides and other agro-chemical products (SNI 241-242) 11.57%	Electricity, gas, steam and hot water supply (SNI 400) 56.57%; Sewage and refuse disposal, sanitation and similar activities (SNI 900) 28.18%
10. Textiles	Machinery for textile, apparel and leather production (SNI 29540) 90.18%; Textile and clothing (SNI 170-190) 9.82%	Textile and clothing (SNI 170-190) 99.94%

The pulp and paper community consists of chemicals, recycling innovations and technical consultancy innovations. Karlsson (2012) and others (Söderholm, 2007) have described the response in the paper and pulp industries resulting in new production, recycling methods. The community centered on foodstuff has involved plastic innovations, cooling and ventilation machinery innovations and methods for food preparation (see e.g. Bäckström et al., 1992; Beckeman & Olsson, 2005; Beckeman, 2008).

The community centered on land transportation is mainly consisting of automotive innovations and parts for automotive cars, including batteries and electrical apparatus n.e.c. The community also involves railway and tramway locomotives and lifting and handling equipment. Suppliers of automotive parts (e.g. Autoliv) and automotive producers (such as Volvo Personvagnar and Saab/Saab Automobile) have formed the basis of strong interdependencies in the development of new technologies (Elsässer, 1995). This community of industries lies at the core of a development block that has been formed around techno-economic problems in the development of e.g. electrical cars, hybrid technologies and catalytic emission control technologies (see section 6.4.3).

A broad development block centered on the diffusion and exploitation of electricity was central in the the second industrial revolution Schön (1990). Enflo et al. (2008) suggested two development blocks centered on electricity in the period 1900-1970. For the period studied, electrical apparatus innovations were not widely used but rather developed for use in electricity distribution, and in the previously mentioned community centered on automotive vehicles. This community should however be understood as the core industries of a broader set of innovations that transcend industry classifications, centered on energy production (see the discussion in section 6.4.2).

Finally, two smaller communities were centered on textiles and clothing, involving a small number of textile machinery innovations, and agricultural and forestry machinery. The latter community has been strongly focused on the problems arising from the shortage of wood during the 1970s, as has been mentioned earlier in chapter 4 and 5.

A qualitative description of the innovations captured by the communities is given in the next section.

6.3.3 Opportunities and problems in communities

The found communities summarize the quantitatively most important patterns of supply and use of innovation across industries. The analysis now turns to a characterization what role technological opportunities and techno-economic problems have played in the communities. This may give an overall view of the qualitative character of the interdependencies in communities. Some of these communities have been more centered on the exploitation of opportunities and others more on the solution of techno-economic problems. Table 6.9 shows the count of innovations exploiting new technological opportunities and problem-solving innovations, by community. The table counts all innovations involved in the community, including innovations for final consumption and general purpose innovations. Some communities consist to a greater extent by innovations exploiting technological opportunities. In particular this applies to the ICT community and the community centered on medical equipment and pharmaceuticals. The ICT community is of special interest. Figure 6.5 shows that both surges of innovations during the structural crisis and the 1990s can be attributed to the exploitation of technological opportunities. There is no increase in the count of problem-solving innovations during the first half of the period. However, during the 1990s the surge can to an almost equal extent be explained by problem-solving innovations.

Four communities emerge as more focused on techno-economic problems: the forestry community, the community centered on construction and metal and wood production, the community centered on automotive vehicles and land transportation, and the community centered on electrical apparatus and energy distribution.

Figure 6.5: Count of innovations in the ICT community by origin, 1970-2007.

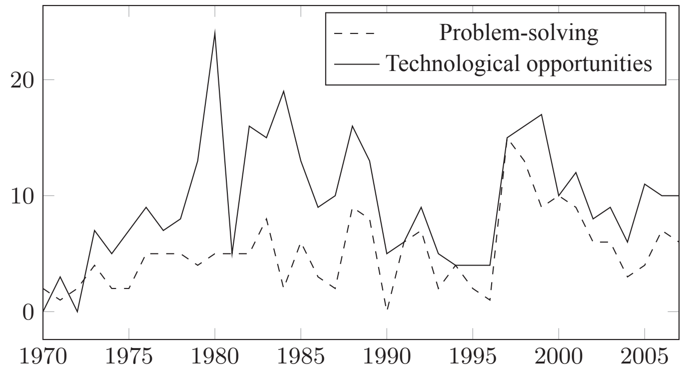


Table 6.9: Count of innovations involved in communities (including innovations for final consumption and general purpose) divided by origin in problem-solving (PS) and technological opportunities (TO).

Community	TO	PS	TO and/or PS	Total count
Pulp and paper	148	114	213	324
Foodstuff	70	96	144	303
ICT	378	206	480	715
Automotive	90	116	176	329
Medical	93	35	104	135
Forestry	7	29	33	55
Construction	154	233	345	642
Military Defence and shipbuilding	21	8	27	69
Electricity	55	68	100	172
Textiles	13	15	24	44
Total	1029	920	1646	2788

6.4 Technological imbalances in the Swedish manufacturing industry

In this section innovations that respond to technological imbalances are discussed. It has been argued previously that groups of industries (communities) characterized by innovations that aim to solve technological imbalances reflect the core dynamics in the evolution of development blocks. These innovations are gap-filling, as it were, bringing forth complementarities that are missing. The extent to which the communities found reflect the bringing forth of complementarities in development blocks can be appraised by a qualitative analysis of the technological imbalances that have engendered creative response. The task of the remainder of this chapter is therefore to analyse and describe the interdependencies between industries in terms of the imbalances that have driven innovation activity. Crucially, this is done by describing historical situations in which imbalances have prompted creative response.

The patterns of innovations responding to critical problems can be understood as centered on a set of problems that are more or less associated with a negative or positive transformation pressure. Some of the communities of problem-solving innovations were characterized by a felt need to overcome a strong negative transformation pressure. Other communities were characterized by entrepreneurial opportunities to solve techno-economic obstacles to the exploitation of new technologies - most notably, the community centered on telecommunication networks and equipment. This section answers the question: What sets of innovations responding to critical problems and technological imbalances can be observed? In doing so, the analysis is guided by revealed community structure, but not limited by it, as there are many cases of problem complexes that transcend the narrow borders of industrial classifications.

In the following sections a large number of cases of imbalances are discussed. Conclusions and an accessible summary of the imbalances discussed is given in section 6.4.10.

6.4.1 ICT: micro-electronics, factory automation and telecommunications

The community centered on ICT innovations summarizes the macrodevelopment block surrounding microelectronics that has been described in chapter 4. Similar to the cases of the steam engine, the dynamo and electricity, the breakthrough of microelectronics was preceded by several decades of discovery and improvement of electronic components and computers. Major breakthroughs in electronics were made with the transistor (1947), the digital computer (1945) and integrated circuits (1961). These innovations resulted from attempts to overcome bottlenecks. The integrated circuit was the response to the increasing complexity of transistor-based systems, what has been called the "tyranny of numbers". The rising complexity made assembly costs high. Moreover, the size of complex circuits impeded efficiency in computers (Langlois, 2002). These problems motivated two Americans, Robert Noyce at Fairchild and Jack Kilby of Texas Instruments, to (independently) develop the first prototypes of integrated circuits. Another key event was the development of the microprocessor, developed by Intel in 1971. Now, the information processing capacity of a digital computer was contained on a single chip and could be mass produced at a low cost. This was the event that finally enabled the wider diffusion of computers and electronics (Bresnahan & Trajtenberg, 1995; Langlois, 2002).

Thus, in the early 1970s an imbalance had been and was being resolved by the exploitation of micro-electronics. Accordingly, the early ICT innovations of the 1970s were to a much larger extent driven by the exploitation of opportunities created by microelectronics than as direct responses to techno-economic obstacles.

However, there are examples of sets of imbalances, which have spurred innovation in the early period. The below description discusses for analytical purposes three parts of the community centered on ICT innovations: 1) a small set of innovations aimed to solve problems in the production and use of electronic components, 2) innovations surrounding factory automation and 3) innovations centered on the production and use of Internet and telecommunications during the second half of the period. The latter is concentrated to the second half of the period, while the first two were concentrated to the first half.

6.4.1.1 Electronic components

Microelectronic components became the "key factor" input in the third industrial revolution (Perez, 1983). Since Swedish industry was not to any great extent geared towards the production of electronic components until the 1990s, such innovations were not numerous. The major producers of electronic components were predominantly American and Japanese (Intel, Motorola, Fujitsu and Toshiba). The Swedish production of electronic components was started in the mid-1970s by Asea-Hafo and RIFA, later restructured as Ericsson Components (Lindqvist, 1992). Asea-Hafo for instance developed and launched a micro-processor in 1976.[7]

A few Swedish innovations during the 1970s and 1980s were directed towards solving critical problems in the development of smaller circuits. A demand emerged in the 1970s for printed circuit boards (PCB) with higher packaging density. The problem with underetching, however emerged as a limiting factor. Perstorp AB was one of several international manufacturers to initiate search for a laminate material with thinner copper plates (*Ny Teknik* 1974:33, p. 10; *Modern Elektronik* 1975:2, pp. 25-26). The thin foil material was launched in 1974. However, due to unsatisfactory results (the innovation failed to reduce the etching time), the search continued and another thin foil innovation for PCBs was launched in 1981 (*Elteknik* 1981:2, p. 61). The shrinking size of transistors and integrated circuits also posed problems in detecting manufacturing errors due to overheating. To solve these problems, AGA adapted its previously developed infrared camera technology "Thermovision" (*Verkstäderna* 1971:11, p. 606).

Micronic, developed a new method, Laserscan, for the production of masks for integrated circuits. The manufacture of masks for integrated circuits with the then available technology (photographic lithography) tended to become a production bottleneck due to the complexity of mask patterns (*Elteknik* 1976:7, pp. 22-28). The method with electron beam lithography later became the primary method, but had not been widely used at that point due to its sensitivity. Instead, the method invented at the Royal Institute of Technology employed a laser technology. After a bankruptcy in 1987, this technology formed the basis of Micronic Laser Systems AB that launched several innovations aiming to overcome obstacles in the manufacturing of masks for ever shrinking electronic components (see also chapter 7). Among these one may mention a laser based lithography equipment for circuit production that aimed to solve the critical problem of steering a mechanical movement with a nano-meter precision. Electron beam methods had solved the problem by increasing the mass on the movable part, which required bulky and costlfy machinery. Micronic Laser System's method was competitive by avoiding bulkiness and costs (*Modern Elektronik* 1990:13, pp. 54-55).

[7] The microprocessor was developed as the result of a collaboration project with Asea's electronics division that was looking for a fast processor for remote control equipment. Intel's microprocessor 8080 was available, but was too expensive (*Modern Elektronik* 1976:19, p. 1; 1976:20, p. 54).

These innovations illustrate early examples of imbalances that appeared in the supply of microelectronics. While not particularly numerous, these innovations illustrate problems that have appeared when the third industrial revolution was underway.

6.4.1.2 Factory automation

The factory automation development block can be characterized as primarily driven by the exploitation of new opportunities from the rapid improvement of microprocessors. As described previously, the microprocessor resolved imbalances in the performance of computers, control and other types of electronic equipment. The major pattern of development during the late 1970s and 1980s was the enabling of a wider diffusion of microelectronics by improvement of performance and cost reduction in electronic components as well as other parts of the factory automation and ICT development block. Examples of innovations aimed to compete and reach new areas of application by improving the performance of control systems and automation equipment are abundant in the SWINNO database. Some of these innovations have been described in section 4.4.1 of chapter 4.

Other parts of the development block however have evolved by way of the solution of imbalances. Technological imbalances have occasionally emerged between the capacity of control systems and the requirements of an applied technology. In these cases the development of micro-electronics enabled the solution of technological imbalances in the 1970s. The introduction and further development of automated guided vehicles (AGV) can be described in this way. The first AGV was commercialized by the US company Barret Electronics in the 1950s (Andersson, 2013). A hampering factor in the development of AGVs was however the limited capabilities and bulkiness of the control systems for the guidance of the vehicles. The solution to these problems was made possible by the advancement of integrated circuits and microelectronics. The Swedish firm, Netzler and Dahlgren (NDC) emerged as one of the pioneers in the development of AGV control systems when it became involved in a Volvo project, which was the first installation of AGVs in Sweden. In 1972 NDC developed the control system for Volvo's carriers (*Ny Teknik* 1976:38, pp. 4-5). As a result of the project Volvo developed and commercialized its carrier technology, for instance at Tetra Pak. NDC was also involved in developing the computerized control system in this project. A subsidiary to Volvo, ACS (AutoCarrier System) was formed in 1976, based on a guided carrier, the so-called Tetracarrier (Elsässer 1995, p. 167, *Automation* 1978:7, pp. 32-34; *Verk-*

städerna 1977:13, pp. 43-45). The further development of AGVs has also been characterized by the overcoming of critical problems. A second generation without rails emerged by the application of various kinds of position technologies. The guide paths were perceived as inefficient and expensive when the users wanted to modify the trucks' movement patterns. Elaborating on a research project at Luleå University of Technology, AutoNavigator developed a laser navigator aimed to enable AGVs without guide paths, thereby overcoming obstacles to attaining more flexible installation (*Automation* 1990:1, pp. 13-15; *Ny Teknik* 1989:40, p. 6; 1992:45, pp. 14, 16; *AGI* 1991:204, p. 66). The navigator was of interest to NDC that had developed a complete control system but was missing the laser navigation component. A collaboration was initiated, which resulted in commercialization (Andersson, 2013). BT Systems developed a similar laser guiding system "LaserLine" that eliminated these problems and obstacles to using AGVs in more demanding areas (*Transportteknik* 1994:10, p. 12).[8]

6.4.1.3 Telecommunications and the deployment of Internet technologies

The major imbalances observed in the broader ICT development block has been the many technological obstacles that appeared in the deployment of Internet and telecommunication networks during the 1990s and 2000s. The history of the Internet deployment and development of telecommunications in Sweden was described in chapter 4 among with a set of firms and innovations that have appeared in the database. The problem-solving innovations in telecommunication components were for the most part aimed at enabling increased transmission capacity of telecommunication networks as it were, resolving bottlenecks that have arisen as the traffic volumes increased. An important driving force in the development of telecommunications and in the deployment of Internet technology has thus been the emerging imbalances between network components, such as circuits and switches, and the network requirements. An early example was the relationship between RIFA and Ericsson in the 1970s and 1980s. RIFA was Ericsson's subsidiary and was one of Sweden's early manufacturers of electronic components. RIFA's development of SLIC (Subscriber Line Interface Circuit) was con-

[8] "Conventional AGVs are almost impossible to use in industries with high hygiene standards - for example in the handling of pharmaceuticals and foodstuff. The rails are difficult to clean and become gathering sites for bacterial growth. [...] In electronics plants and other facilities with special flooring and where handling requires anti-static environments, path guided AGVs are difficult to use" (*Transportteknik* 1994:10, p. 12; translation by the author).

tracted in 1979 by Ericsson and Televerket for the well-known AXE system. The circuit was needed to accommodate the problem of alignment between analogue lines and new generation of digital switches.[9]

In the 1990s, after the deregulation of the telecommunication markets, the venues for infrastructure investment in Internet and Telecommunications opened up. Innovations solving critical problems in the deployment of Internet and Telecommunication networks include transmission systems and transmission technologies, network switches and electronic components for data and telecommunication networks. Most of these innovations can be understood as responding to obstacles in the introduction of new communication technologies, such as broadband access technologies DSL (Digital Subscriber Line) and the telecommunication transmission standard, ATM (Asynchronous Transfer Mode) or in the later introduction of Voice-over-IP (VoIP).

The development of ADSL technology (Asymmetric Digital Subscriber Line) commenced internationally to address a capacity bottleneck (Fransman, 2001, pp. 125-126). When Telia was the first in the world to transmit high resolution TV images using VDSL (Very high speed digital subscriber line) it was noted that modems and network components were necessary for a commercially functioning technology (*Ny Teknik* 1997:15, p. 4). In 1999 Telia Research could launch a series of chips adapted for VDSL, developed together with the French chip manufacturer ST Microelectronics (*Ny Teknik* 1999:45, p. 11).

ATM (Asynchronous Transfer Mode) was developed to fulfil the requirements of broadband, enabling digital transmission of data, speech and video and to unify telecommunication and computer networks. For this technology, fast circuits were needed. Ericsson developed an ATM circuit, AXD 301 for broadband networks aimed to increase performance and fulfil security requirements (*Ny Teknik* 1994:19, p. 4). Netcore (later renamed Switchcore) launched a circuit that could handle both ATM and IP technology. The technology came from a research project in which Ericsson Com-

[9] "In 1979, Rifa was contracted to develop SLIC, a special circuit for the modern AXE telephone exchanges. AXE is Televerket's and Ericsson joint telephone system. The requirements for what SLIC will manage have been designed by Ericsson and Telecom's joint development Ellemtel. [---] Every year the world's network grows with some thirty million lines. This will double the number of lines connected to private bills of companies, organizations and government agencies. More and more of these switches are entirely digital. Meanwhile, almost all connected lines are still analogue. To achieve alignment between the digital and the analogue technology in principle a circuit of the SLIC type is needed for every line connected" (*Ny Teknik* 1985:24, p. 30; translation by the author).

ponents, Saab Dynamics, the Royal Institute of Technology and the Universities of Linköping and Lund participated (*Elektroniktidningen* 1997:19, p. 4; *Ny Teknik* 1998:25-32, pp. 16-17). The circuit was customized for IP switches and routers for the Gigabit Ethernet standard. With increased traffic, the data switch was a capacity bottleneck, but with Netcore's circuit it became possible to build faster and cheaper switches. Optotronic developed a circuit for data communication in fiber optic networks, Ethernet in particular (*Ny Teknik* 2000:35, p. 16). The lack of network processors compatible with the requirements of fast routers, prompted Xelerated to develop and launch a network processor capable of 40 Gbyte/second in 2006 (*Ny Teknik* 2001:22, pp. 12-3; 2002:20 Part 2, p. 7; 2007:20, p. 12).[10] The firm also developed the world's fastest programmable switching circuit for Ethernet (*Ny Teknik* 2005:38, pp. 8-9).

The innovations of Dynarc and its sister company NetInsight, stemmed from the research group at the Royal Institute of Technology that since the 1990s developed DTM , Dynamic Synchronous Transfer Mode - a network protocol enabling high speed data switching and increased capacity in IP networks. Net Insight launched a network technology able to provide speeds of several terabits per second (*Ny Teknik* 1998:25-32, pp. 16-17). Dynarc also developed a PBX for IP networks based on DTM commercialized in 1998 (*Telekom idag* 1998:8, p. 11; *Ny Teknik* 1998:25/32, pp. 16-17).

In 2000 Ericsson launched the world's first router for wireless Internet (called RXI 820). Traffic in mobile networks were growing and operators encountered the difficulty of attaining high speech quality while making efficient use of the networks. So far, routers were not able to supply the same speech quality as AXE switches. This however was a necessary requirement if wireless Internet were to become a reality. The new router was developed to overcome these difficulties (*Ny Teknik* 2000:5, p. 8; *Telekom idag* 2000:2, p. 32).[11]

[10] "According to Johan Börje the problem with today's network processors are that the programs cannot be run rapidly enough. For really fast routers only custom-made circuits that are specially adapted. - They are expensive and take long time to develop. Moreover, they are not flexible since they cannot be re-programmed" (*Ny Teknik* 2001:22, pp. 12-3; translation by the author).

[11] "So far, routers have not been able to give the same speech quality as AXE switches. Especially not with the relatively slow transmission by radio in a mobile network. A delay of a few milliseconds is enough to disrupt the speech quality. In particular if the delay becomes inconsistent, because some packages have taken a different route or been troubled by an overburdened connection. Ericsson's new router solves the problem by sorting the traffic and by responding to such emails and numbers in different ways. E-mail is sent over

By the end of the period Skype, a new-to-the-world service innovation was launched, exploiting the Internet infrastructure and the Voice-over-IP (VoIP) technology (*Telekom idag* 2005:4, p. 47; 2005:8, p. 38; 2006:7, pp. 38-9). The introduction of mobile Voice-over-IP technology was however shaped by obstacles, in particular since the technique was developed for data transmission and not speech traffic. Other development projects were aiming to overcome such obstacles in the introduction of VoIP technology. Ericsson Research was developing a technology "to solve the basic problems with the mobile Internet" (*Ny Teknik* 2000:41, p. 22; 2000:42, p. 16; 2001:41, p. 10; translation by the author). A major problem was that IP phones would be more expensive to use than GSM mobiles, if the then-available Internet technology was used. The result was an IP-protocol that could solve transmission problems and could double the capacity in mobile IP networks. Nanoradio was started in 2004 to solve the problem of how mobile phones could cope with VoIP. The then-available wlan circuits were power consuming and Nanoradio developed a small wlan circuit that enabled a fast synchronization of mobile telephones (*Ny Teknik* 2005:17 "IT", p. 14; 2006:8, p. 4; *Telekom idag* 2005:1, p. 19).

Several innovations were aimed to use or for use in Wave Division Multiplexing (WDM), a technology where data signals are transmitted in the same fibre cable. By sending them with different wavelengths, disturbances between the signals could be avoided. WDM enabled increased traffic in optical networks and the addition and switching between wave length to different users without having to replace physical components. Altitun was founded in 1997 by researchers at the Royal Institute of Technology to commercialize a tunable laser, aim to become a key component in fiber optic broadband networks using WDM (*Ny Teknik* 1999:47, p. 13; 2003:43 Part 2, pp. 8-9). Altitune's laser however never reached commercialization.[12] Syntune continued the development of the core technology, a tunable laser that enabled network operators to switch wavelengths (*Elektroniktidningen* 2003:14, p. 8; *Ny Teknik* 2005:6, pp. 16-17). Another of the early entrants, Phoxtal Communication, developed a wave length switch for optical fiber networks to solve a technical problem in wave length multiplexing (*Ny Teknik* 2004:14, p. 10). The origins of Lumentis was that former Ericsson engineers had observed traffic problems and the need to connect remote

the Internet as a large package. It does not matter to the receiver if the packets suffer an additional delay of a few seconds. Speech and video is sent as small data packet, which is afforded special priority by the network" (*Ny Teknik* 2000:5, p. 8; translation by the author).

[12]During the hiatus of the IT bubble, Altitun was sold to an American firm, ADC.

networks to metropolitan area networks so that operators effectively can reach their end customers. In 2000 they started development of a DWDM (Dense Wave Division Multiplexing) solution for metro networks that do not require optical amplifiers (*Elektroniktidningen* 2001:15, p. 6; *Ny Teknik* 2002:16 Part 2, p. 10; 2002:43, pp. 8-9). Lumentis was in 2005 fused with another Swedish firm, Transmode. The new firm, also called Transmode, became a pioneer in enabling the introduction of Wave Division Multiplexing, by its development of iWDM (Intelligent Wave Division Multiplexing) in 2005 (*Ny Teknik* 2005:50, p. 2).

6.4.1.4 Secure transmission and identification

Internet and data communication security may be seen as an imbalance that spurred innovation activity, in particular during the 1990s and 2000s. Algonet, the firm that first made Internet publicly available in Sweden, recognized a problem with unsolicited bulk e-mails and developed an electronic filter to prevent it (*Ny Teknik* 1997:24, p. 2). In 1997, Ericsson launched a new modem with built-in encryption for secure Internet transmission (*Ny Teknik* 1997:4, p. 6). As more people began to use the Internet, and as more transactions were carried out over the Internet, the security problem became an issue. Some firms emerged attempting to eliminate obstacles to e-commerce, e.g. Surfbuy and Buyonnet. The breakthrough of e-commerce was considered to be hampered by the problem of attaining secure transactions. Surfbuy was started in 1999 to provide systems for secure transactions where the buyer and seller were given direct access (*Telekom idag* 2000:6, p. 30). World Wide Link Sweden AB developed a system, "@-girot", for secure payment (*Verkstäderna* 2002:10, pp. 21-24). Other firms developed systems for secure identification online or in mobile phones, selling their services for banks. Other security issues pertained to the use of mobile telephones. Fingerprint Cards and Prosection are firms notable for developing biometric systems (e.g. Fingerprint Cards' fingerprint recognition system for mobile telephones).

6.4.1.5 Summary

During the 1970s and 1980s innovation activity in the burgeoning ICT development block was to a much larger extent driven by technological opportunities than technological imbalances. The examples given were of a small set of innovations responding to obstacles to the introduction of AGVs and problems in the production of printed circuit boards (PCB). By contrast, in the second half of the period, technological imbalances in the deployment of Internet and telecommunication networks spurred a large number of innovations.

6.4.2 Critical problems in Energy production and distribution

The community centered on energy distribution contains in fact several areas of related problem-solving innovation activity. It is clear however that energy production and energy distribution innovations transcend industrial classifications of supply and use. It is possible to identify two areas of innovation activity connected to energy distribution. One has concerned the supply of electrical apparatus innovations, and the development of power production plants for use in energy production. A second set of innovations have been formed around the development of renewable energy technologies, such as wind power, solar energy and biomass, and have concerned a broader set of industries and product groups.

6.4.2.1 Electricity and energy production

The first set of the above-mentioned innovations are well described by the community centered around energy production. These innovations may be ascribed to traditional industry linkages between producers of electrical apparatus, energy producers, and final users of energy. From the early decades of the 20th century a development block was taking shape around the diffusion of electricity and energy production. The phenomenon of electricity was known long before its economic breakthrough, but it was in the 1890s that innovations of alternating current in a three-phase system solved the critical problem of transforming higher and lower voltage.[13] This meant that the transfer losses could decrease at higher voltages and that electricity could be transferred across greater distances. During the following decades the price of electricity decreased, enabling a wider expansion of electricity (Ljungberg, 1990; Schön, 1990). A traditional "development pair" of importance in this development block were Asea (later ABB) and the Swedish State Power Board, Vattenfall. Asea and Vattenfall's cooperation was initiated in 1908 when Asea delivered high voltage circuit breakers to Trollhättan's canal and hydro power plant, reconstituted in 1909 as Vat-

[13] The three-phase electric power system was independently pioneered, among other inventors, by Jonas Wenström. Jonas Wenström's innovations were instrumental in the formation of Elektriska AB, later Allmänna Svenska Elektriska AB (Asea) in 1883 (Schön, 1990).

tenfallsstyrelsen (abbreviated Vattenfall) (Fridlund, 1994, pp. 107-108). In the the post-war era, Asea developed HVDC (High Voltage Direct Current) technology with Vattenfall as the main user (Fridlund, 1997). In March 1954 transmission between Sweden's mainland and the Gotland island began (Fridlund, 1997, pp. 30-31). The development of HVDC transmission technology is also an example of how innovation has required the solution of critical problems of different types: technical, economic as well as institutional (see Fridlund, 1997 for a detailed account).

During the period studied, electrical apparatus innovations have solved problems for the wider use of various energy production and distribution technologies. A disadvantage with HVDC technology was that it is difficult and expensive to build branches from DC lines. HVDC was a costly and complex technology, profitable only for large power transfers or long submarine cables. ABB's HVDC Light, launched in 1997, was aimed to enable the use of HVDC in other utilities, making it possible to build branches lines and connect DC networks to AC networks (*Elektroniktidningen* 1997:11, p. 28; *Ny Teknik* 1997:20, p. 7). ABB's major innovation Powerformer was, like some of the previously mentioned innovations, developed in collaboration with Vattenfall, based on the ideas of the inventor Mats Leijon. This innovation solved an old bottleneck that had limited the use of generators at high voltage alternate current transmissions. The problem lay in the requirements of isolation. Before Powerformer, the limit of the voltage a generator could provide was in the vicinity of 20 kilovolts. Leijon's idea was to make use of standard cables for high voltages for isolation. Powerformer enabled direct connection into the high voltage power grid, thereby avoiding maintenance costs and efficiency losses (*Verkstäderna* 1998:4, p. 15; *Ny Teknik* 1998:9, p. 7; *Automation* 1998:3, p. 12; see also Fridlund, 2007, pp. 267-274). The technology underlying Powerformer enabled a transformer, Dryformer, that by being oil-free was rid of the risk of oil leakages, fires and explosions. A wide range of applications became possible, e.g. in residential areas and environmentally sensitive applications.[14]

Several innovations were developed by Asea/ABB to overcome problems with power failures and voltage fluctuations in the electricity networks. This became an important problem to solve with the entry of electronics into industries, since electronic equipment and computers are especially sensi-

[14]Two other following innovations were also applying the same technology: a motor, Motorformer (*Kemivärlden* 2001:3, pp. 41-42; *Verkstäderna* 2001:4, pp. 28-29; *Ny Teknik* 2001:8, p. 10) and a wind power generator, Windformer (*Kemivärlden* 2001:3, pp. 41-42; *Ny Teknik* 2001:8, p. 10; 2002:10, p. 7).

tive. On the initiative of customers, Asea/ABB's relay system "Switchsync" was developed in the 1980s to solve problems with voltage fluctuations that caused computers to shut down (*Ny Teknik* 2006:10, p. 9). ABB Control developed an is-limiter for similar reasons (*Automation* 1992:1, p. 16; *Verkstäderna* 1991:13, pp. 68-69).[15] The increased requirements for computer servers and problems with power failures prompted Netpower Labs to develop a failure-free electricity distribution system (*Telekom idag* 2007:4, p. 39).[16]

A smaller set of innovations observed in the SWINNO database have been developed for nuclear power plants. The introduction and use of nuclear power necessitated development efforts to ascertain the security in nuclear plants and develop technology for the handling of nuclear waste. AB Atomenergi (later renamed to Studsvik Energiteknik) was a partly state-owned company established in 1947, that was assigned the role of developing and introducing nuclear power in Sweden. Innovations launched by AB Atomenergi or Studsvik Energiteknik were in part aimed to overcome security problems in nuclear power production. AB Atomenergi developed a method to refrain fuel rods in nuclear power plants from failing. Previously, accidents due to unexpected failure of fuel rods had led to radioactivity leaks into the reactor cooling circuit (*Ny Teknik* 1972:40, p. 1). A dosimeter system was also constructed to enable the measurement of radio activity in the environments of nuclear power plants (*Ny Teknik* 1975:30, p. 4). Concerns about the emergence of cracks in pressure vessels for nuclear power plants spurred Studsvik Energiteknik to develop pressure vessels that could withstand high pressures and temperatures (*Ny Teknik* 1980:28, p. 7).

[15] "Short circuits are a calamity that damage electrical and electronic devices, particularly noticeable in complex production processes and entail significant costs for unplanned downtime e.g. in process industries. Therefore over-dimensioned circuit breakers, is-limiters and contact systems are often installed. When a short circuit occurs the amperage instantly increases from e.g. 20 A to over 200 kA. This forms an arc that increases with the resistance that lowers the amperage down to 0 at worst By then, contacts have may have welded together and connected equipment may have been destroyed. [---] ABB Control AB [...] began a year ago to look into alternative solutions" (*Automation* 1992:1, p. 16; translation by the author).

[16] "A functioning electricity supply is essential in all industries, and a power outage could mean big financial losses for the company. Even in areas such as IP telephony, it is important that the servers are functioning. Netpower's solution is to have developed a new type of uninterruptible power supply, which provides the servers and other types of equipment with direct current instead of alternating current. The problem with the AC line is that it is not always available and when needed batteries as backup" (*Telekom idag* 2007:4, p. 39; translation by the author).

AB Atomenergi also developed and launched other innovations in different but related fields. For instance, the company developed a needle detector in 1964 aimed for medical detection of radio activity. The detector was improved and was in 1971 launched as a routine instrument for medical research (*Ny Teknik* 1971:21, p. 4). AB Atomenergi also developed a gamma-ray based densitometer for medical purposes (*Ny Teknik* 1971:35, p. 4).

Asea-Atom was formed in 1969 by the merger of AB Atomenergi's nuclear fuel production activities and Asea's nuclear power activities (*Ny Teknik* 1972:40, p. 1). In 1976 Asea began to investigate the possibilities of using its high pressure technology to solve the problem of the safe handling, containment and storage of nuclear waste (*Verkstäderna* 1977:3, p. 9; 1977:7, p. 15). A critical problem in the use of high pressure technology to develop such methods was the development of a corrosion resistant material. In 1978 Asea launched a container for spent nuclear fuel based on aluminium oxide (*Verkstäderna* 1978:9, p. 39).

6.4.2.2 Electric motors

Since the 1970s engineers have attempted to adapt AC motors to electronic systems. However, in contrast with DC motors, the motor speed is difficult to control and has required separate variable frequency controls. This has acted as a hampering factor to the use of AC motors.[17] Several Swedish innovations have from the late 1980s been developed to overcome these difficulties. Based on a technique called polar regulation, Styrkonsult developed a method for motor speed control aiming to overcome these difficulties for asynchronous motors (*Elteknik* 1989:10, pp. 22-24). Some firms developed variable speed drives (VSD), e.g. ABB Drives' VSD for speed and torque control launched in 1992 (*Automation* 1992:7, p. 27). Emotron AB developed a drive system for synchronous motors with VSD that enabled the attainment of higher speeds (*Automation* 1993:6, pp. 8, 12; *Ny Teknik* 1996:17, p. 8). However VSDs were expensive and limited the use of AC motors. Other solutions have come to be explored. Based on scientific research in Lund aiming to solve the critical problem of motor speed

[17] For instance, the state of so-called asynchronous motors in the late 1980s was described in one of the articles (*Elteknik* 1989:10, pp. 22-24). The lack of a theory for the behavior of asynchronous motors hampered progress in speed regulation since its invention. A vector model was developed in Western Germany during the 1970s, which enabled a wider use of asynchronous motors. However, DC motors were still superior in terms of fast and precise speed control.

control, NFO Drives developed and commercialized a control chip for electric motors that lowered the costs for speed control (*Automation* 1994:6, pp. 25-26). The underlying principle was invented by Ragnar Jönsson, a method called "Natural Field Orientation" (*Elektroniktidningen* 1994:16, pp. 26-27; *Verkstäderna* 1994:9, p. 88; *Ny Teknik* 1997:11, pp. 36-37; *Verkstäderna* 2000:8, p. 75; *Energi & Miljö* 2000:8, pp. 60-61; *Svensk Papperstidning* 2001:1, p. 42). ABB Motor's "integral motor" was built on integrating the VSD into the motor, thereby avoiding unnecessary consumption of electricity (*Ny Teknik* 1996-48, p. 30; *Automation* 1997:1, p. 14). ABB also developed drive systems (ACS 600, ACS 1000 and ACS Multidrive) enabling variable speed drives, exploiting a new direct torque control technology (*Automation* 1995:5, pp. 34-35; 1996:1, pp. 30-33; 1998:1, pp. 29-30; 1998:5, p. 17; *Ny Teknik* 1995:16, pp. 14-5). ACS 1000 for instance enabled speed control at high voltages.

6.4.2.3 Heating pumps and Renewable energy technologies

Following the oil crisis search *en masse* for new energy technologies was initiated. Some examples of energy technologies developed during this period were

- heating pumps,
- innovations for the use of biomass (e.g. wood and forest residue) and peat
- innovations for the use of solar power
- innovations for the use of wind power.

These were all technologies characterized by their own imbalances and obstacles.

Heating pumps were developed and diffused rapidly after the structural crisis of the 1970s. The oil crisis and the increased energy prices were contributing factors to that heating pumps became an economically feasible alternative (Kaijser et al., 1988, pp. 76-92). The heating pump technology reinforced and enabled established energy distribution systems, electric heating and district heating, to be developed further. An example is Stal-Laval Turbin AB that in 1974 started to study alternatives for heating through district heating systems. Heating pumps were found to be an environmentally friendly solution, that also enabled the use of domestic energy resources. Driven by the aim to decrease oil dependency, the firm therefore developed a heating pump, launched in 1982 (*Ny Teknik* 1982:41, p. 41; *Verkstäderna* 1982:12, pp. 21-23). There were however techno-economic obstacles to be overcome. One of the earlier examples is Kryotherm that attempted to construct a standard device for warehouses, public facilities and houses. Earlier attempts to construct an economic standard device had failed due to technical construction problems (*Ny Teknik* 1972:14, p. 16). Moreover, most heating pumps tested in Sweden had not worked in temperatures below -5 ° C. Thermia therefore developed a heating pump aimed to work all year, taking its heat from the ground (*Ny Teknik* 1976:31, p. 24). Fläkt Evaporator similarly developed a heat pump capable of heating and preparation of hot tap water down to an outside temperature of 3 ° C (*VVS & Energi* 1983:1, p. 7).

Innovations surrounding the production of power using biomass are observable in the SWINNO database from the 1980s. According to Jacobsson (2008) the biomass innovation system underwent a formative phase in the 1980s and 1990s. Several innovations in the database were developed aiming to overcome techno-economic obstacles to the use of various forms of bio-energy, e.g. from forest residue, peat and recycled biological waste.

Wood and forest residue was one of the main alternative fuels. The previously noted urge to make better use of wood material was driven by a wood shortage during the 1970s, but also the growing demand for chips for energy production. This led to the development of methods that attempted to make profitable the processing of forest residue. Such machinery innovations have been discussed in chapter 4. Other examples were Bruks Mekaniska AB that developed a bio-energy production system based on a bunch delimber, developed with the Swedish Forest service and Billerud forest industries (*Svensk Trävaru- och Pappersmassetidning* 1985:9, p. 45). In 1975 the Swedish government gave the Board for Energy Research (Nämnden för Energiproduktionsforskning) the task to lead and coordinate research in energy production, *inter alia* the development of agriforestry for the production of biomass. Profitable agriforestry required the solution of techno-economic obstacles. Two observations on development projects are contained in the SWINNO database. Commissioned by the board for energy production research, Sikob developed machinery for large scale energy forest , as large scale production was necessary to achieve profitability (*Sågverken* 1980:10, pp. 65-73; *Ny Teknik* 1980:45, pp. 8-9). Ergonomi Design Gruppen developed machinery for smaller energy forests in abandoned arable land (*Sågverken* 1980:10, pp. 65-73). Supported by the Board for Energy Research, Sikob also developed machinery to make profitable use of combustible material such as branches and tree tops (*Sågverken* 1986:2, pp. 13-17).

A few innovations were developed to enable the use of peat as a fuel source. Vyrmetoder developed a method to extract methane gas from peat *in situ*. A problem was that other methods for extracting methane gas were damaging for the environment (*Ny Teknik* 1981:42, p. 11). Studsvik AB developed a method for the production of methanol from peat or biomass (*Ny Teknik* 1983:35, p. 8).

Swedish firms have been pioneers in technology to use gasified biomass (Johnson & Jacobsson, 2001). In the mid-1980's SKF Steel had developed its gasification process Plasmadust (*VVS & Energi* 1983:2, pp. 83-84; *Jernkontorets Annaler* 1983:2, pp. 22-23; *Kemisk Tidskrift* 1983:2, p. 17) which enabled the use of coal based fuels, e.g. peat, and biomass in energy production. Studsvik AB developed a technology for electricity generation with gasification of biomass.[18] Termiska Processer i Studsvik (TPS) developed a gasification technology for biofuels (*Ny Teknik* 1995:36, pp. 24-25; *Ny Teknik* 1998:24, p. 10).

Other innovations were aimed to produce biofuel from residue from the pulp and paper industry. Costly recovery boilers have been a bottleneck in the gasification of black liquor, a residue from pulp production. The Chemrec process (developed by a firm with the same name) was aimed to replace the recovery boilers and enable increased energy efficiency (*Ny Teknik* 1990:16, p. 5; *Svensk Papperstidning* 1991:10, pp. 32-33, 35-36, 39-40; 1994:7, p. 50; 2001:7, p. 24; 2001:7, pp. 48-50; *Kemisk Tidskrift* 1990:5, pp. 20-21). LignoBoost AB developed a method to extract high grade biofuel from black liquor. While enabling purer black liquor, the process was primarily motivated to improve profitability and overcome the bottleneck of the costly recovery boilers (*Svensk Papperstidning* 2006:7, pp. 14-16; 2007:2, p. 46; *Ny Teknik* 2006:23, p. 6).

The first firm to mass-produce solar collectors in Sweden was Teknoterm, launching a system for water heating with solar energy in 1977 (*Verkstäderna* 1977:7, p. 54). A techno-economic obstacle to the introduction and use of solar energy was the limited sun exposure during winter time, when the demand for heating is the largest. Therefore, technologies had to be developed

[18] Earlier attempts with gasified biomass had often failed due to that gases created in the process contain troublesome tar compounds. Studsvik solved the problem with a cheap and easy method. After gasification tar molecules are broken down to much more manageable molecules such as carbon monoxide, hydrogen and methane (*Kemisk Tidskrift* 1991:10, pp. 24-26).

to enable seasonal and long term storage of summer excess energy. Sol-Lab Linköping developed a solar collector within a broader development project aimed to test and assess seasonal storage of thermal energy (*VVS* 1979:12, pp. 48-49). A residential area in Lambohov, Linköping with about 55 houses was heated with the help of solar collectors. The project was the world's largest solar energy project of its kind. Aluminiumteknik, a subsidiary of Gränges Aluminium, had developed a solar collector absorbent that fulfilled the necessary requirements of lifelength and was used in the project for the development of the solar collectors (*Automation* 1979:2 pp. 21-22; 1979:4, pp. 33-34; *Jernkontorets Annaler* 1979:1, p. 59). It was during the oil crisis that Gränges Aluminium started development of absorbants for solar collectors (*Verkstäderna* 2003:10, p. 18).[19] AGA Heating developed a complete solar energy system, including a solar collector, that was specifically adapted for the Swedish conditions (*Automation* 1978:6, pp. 17-18). A development firm, Sunroc, was formed by Innovation Thomas Nilsson AB together with the corporate groups Euroc and Kemanord to commercialize a solar energy system capable of all-year heating of houses (*Kemisk Tidskrift* 1977:11, p. 13; *VVS* 1977:10, pp. 9, 16). Tepidus developed a chemical heating pump capable of long-term energy storage to enable heating by natural energy sources (*VVS* 1979:12, pp. 42-43).

Solar cell's were still at the end of the period too expensive to be considered a viable alternative renewable energy source. In the 2000s however the market for solar cells grew rapidly, primarily because of subventions for solar cell use in Germany and Japan. Towards the end of the period studied one may observe several innovations responding to the renewed interest in solar power. Climatewell developed a thermochemical accumulator to solve the problem of chemical energy storage, eliminating heat loss during the storage (*Ny Teknik* 2002:33, p. 4; 2004:49, p. 8; 2006:18, p. 26). Arontis developed a solar collector able to produce both warmwater and electricity (*Ny Teknik* 2007:23, p. 20; 2007:24, p. 20). Midsummer developed a process for the production of solar cells inspired by the production of semi-conductors (*Ny Teknik* 2007:8, p. 22). Other innovation projects were initiated (but not commercialized during the period), e.g. Solibro's thin film solar cells.

Following the oil-crisis, wind power technologies began to be explored on a global scale. In Sweden, a wind energy programme was supported until the mid-1980s. Government funding was for instance granted in 1975

[19]This part of Gränges' activity later became Sunstrip that continued to develop absorbents for solar collectors (*Verkstäderna* 2003:10, p. 18).

for Saab-Scania to develop Sweden's first wind turbine (Bergek & Jacobsson, 2002; *Ny Teknik* 1976:41, p. 22). However, lack of legitimacy and political decisions led to reduced ambition in the mid-1980s (Bergek & Jacobsson, 2002). Struggling with a lack of resources, a handful of firms developed wind power technologies and wind turbines from the 1990s and on. Nordic Wind Power's development project was aimed to construct a wind turbine for use in midland areas and adapted for unfavorable wind conditions (*Verkstäderna* 2002:10, pp. 18-19). VG Power responded to the high costs of wind power and developed an electricity generator for wind turbines (*Ny Teknik* 2004:39, p. 5; 2007:7, p. 28; 2007:39, pp. 8-9).[20]

In sum, the technological imbalances observed in the field of renewable energy may be characterized as following a pattern over time in which the obstacles have shifted focus from pertaining to the technical viability of technologies, to their wider adoption in firms and society. Following the oil crisis obstacles to the development of renewable energy technologies were primarily technical in character. Biomass energy became the major alternative energy source. Towards the end of the period studied, a resurgence in renewable energy technologies may however have begun to take place. New Swedish firms have developed innovations in the areas of solar energy and wind power and other so-called "cleantech" innovations.

These areas had still techno-economic obstacles to be overcome. Arguably, "carbon lock-in" (Unruh, 2000), may pose more serious obstacles to the wider use of renewable energy technologies.

6.4.3 Automotive vehicles and land transportation

The unsatisfactory treatment and the adverse effects of emission and vehicle exhaust form an imbalance at the core of the community centered on automotive engines, batteries, automotive vehicles and land transportation. This community contains several interrelated innovations that have emerged to solve the issue at hand. One may point at two parts of this development block. The first part, encompassing a larger number of innovations,

[20] In an article the problem is described: "Wind power is expensive today. Therefore, gear switches that change up the rotor blade speed of most wind turbines are not popular among the power companies. They are a common cause of costly breakdowns. A less common alternative is to use direct-driven generators without gearbox. The catch is that they are heavy and therefore expensive. That is the problem VG Power has solved with a patented technology developed by wind consultant Staffan Engström" (*Ny Teknik* 2007:7, p. 28; translation by the author).

is centered on emission control technology and innovations introduced to decrease vehicle exhausts for gasoline driven vehicles. Another set of innovations have been aimed at overcoming obstacles to the introduction of electrical or hybrid vehicles and technologies.

6.4.3.1 Emission control technology

The attainment of improved emission control and reduced exhausts has required the interplay between car and truck producers and producers of catalytic converters, drive and control systems and motor engines. The increased effects of air pollution spurred new legislation and research to reduce pollution in the 1960s (Elsässer, 1995; Bauner, 2007). The US was in many aspects a precursor in the sharpening of vehicle exhaust legislation. Swedish legislation often followed its example. The introduction of exhaust requirements and legislation in the US had an impact on the introduction of emission control technologies, also in Sweden (Elsässer, 1995; Bauner, 2007). Saab-Scania and Volvo were two early Swedish contributors. They separately developed three-way catalytic converters (TWC), introduced in new car models for the US market in 1976 (Elsässer, 1995; Bauner, 2007, pp. 254-255; *Verkstäderna* 1988:12, pp. 93-94).

The introduction of TWC in Europe however faced hurdles to be overcome. In particular, the introduction of TWC required the availability of unleaded fuel, as lead contaminates and prevents catalysts from treating the exhaust. This process was slow in Europe. In Sweden, unleaded fuel gradually became available from 1986. In 1986 the Vehicle Exhausts Act was passed by the Swedish parliament. It meant the introduction of requirements for emission control for new cars (*Kemisk Tidskrift* 1985:13, pp. 10-14; 1987:10, pp. 48-49). TWC equipped vehicles were available on the Swedish market in 1986 and TWC was made mandatory in 1989 (Bauner, 2007, pp. 257-258). In 1988 Saab-Scania launched an improved emission control technology based on TWC and unleaded fuel, adapted for the Swedish climate and driving conditions. The system was introduced on all car models with 16-valve engines (*Verkstäderna* 1988:12, pp. 93-94). An injection engine constructed for unleaded fuels and catalytic emission control was launched in 1989 (*Verkstäderna* 1989:12, p. 66).

Emissionsteknik (Svenska Emissionsteknik) was one of the Swedish actors to develop catalytic emission technology innovations as a subcontractor to the automotive production industry. The firm was formed in 1985 by AB Torsmaskiner and Eka AB to produce a catalytic converter for the automotive industry (*Kemisk Tidskrift* 1985:13, pp. 10-14; 1987:10, pp. 48-49).[21] One of the driving forces was the anticipation of new legislation. The development of catalytic converters have however faced several technical problems, some of which are still unsolved. A critical problem is to combine the reduction of NO_x with the reduction of particle emission. Another problem was to combine catalytic soot combustion with catalytic reduction of NO_x in a system. Another was the effect of accelerated oxidation of nitrogen monoxide to nitrogen dioxide, which can produce acute toxic effects on people in urban areas (*Kemisk Tidskrift* 1988:8, pp. 6-8). In 1994 Emissionsteknik launched a system capable of soot combustion during normal operation (*Ny Teknik* 1994:45, p. 6).

After Sweden's entry in the EU in 1995, EU's emission standards have applied. These have to some extent set the pace of innovation activity. Two technologies were capable of meeting the Euro 4 requirements for NO_x emissions coming into force in 2005: the EGR (Exhaust Gas Recirculation) and SCR (Selective Catalytic Reduction) technologies (*Transport idag* 2004:5, p. 8). EGR had been introduced in Sweden following regulations of 1977 (Bauner, 2007). To meet the requirements of Euro 4, and the later Euro 5 requirements, Scania developed several innovations, building on EGR technology. EGR technology and Scania for instance launched the first diesel engine without additives, complying to the Euro 4 requirements. The Euro 4 engine was based on EGR technology and aimed to accomodate the critical problem of reducing both NO_x and particle emissions (*Transport idag* 2005:4, p. 23). STT (Svensk Turbo Teknik) developed a technology to diminish NO_x emissions from heavy diesel engines, based on EGR. The problem with turbo-equipped trucks and bus diesel engines was that surplus oxygen from the combustion produce NO_x emissions (*Kemivärlden* 2000:10, p. 12). EGR technologies however had some drawbacks. Varivent's innovation was developed to solve the problem of energy losses in EGR technologies (*Kemivärlden* 2003:8, p. 16; *Ny Teknik* 2003:1-3, p. 12; 2006:10, p. 4).[22]

[21] Eka's research on catalysts began when it sold a subsidiary, Katalistiks to Union Carbide, which left excess resources in the area (*Kemisk Tidskrift* 1985:13, pp. 10-14).

[22] "The increasingly stringent emission limits in the United States, Japan and Europe are forcing truck manufacturers to develop new emission control technologies. EGR (Exhaust Gas Recirculation) is one of the main tracks and are used for example both by Scania and Volvo. When fresh air is mixed with the exhaust gas, the cylinder mass increases and the combustion temperature in the engine is reduced, which in turn reduces nitrogen oxide emissions. A problem with the EGR is that the exhaust gases have lower pressures than fresh air. It leads to increased fuel consumption, since the exhaust gases must be pumped back to the

SCR technology was being introduced in Europe in the beginning of the first decade of the 21st century. Emission Technology Group developed a system that was capable of upgrading old motors to the new technology (*Transport idag* 2004:11, p. 7). Volvo Lastvagnar's new truck, Volvo FH16, was equipped with SCR technology and AdBlue and could thereby pass Euro-4 requirements (*Transport idag* 2006:3, p. 12; 2006:8, pp. 20-21). SCR faced however acute techno-economic obstacles to its introduction. The catalyst required the use of urea (Adblue), and therefore required tanking systems and the distribution of urea. In the SWINNO database, one example can be found of a Swedish firm that responded to these problems. Identic developed a system for closed refuelling (*Transport idag* 2004:5, p. 8) to solve some of the problems with AdBlue. The closed refuelling system was developed to eliminate the risk of spill and preventing AdBlue from freezing at low temperatures and from air contact to due the tendency to crystallization that result from air contact.[23]

Beside emission control technologies, other innovations have been necessary to attain reduced emissions. Innovation in fuel injection systems, drive and control systems have been complementary to the development of emission control technologies.

6.4.3.2 Methanol and alternative fuels

Innovations were also aimed to enable the use of alternative energy sources for vehicles, such as methanol. While, other alternative fuels were considered, methanol dominated the research efforts during the 1970s and the 1980s (Sandén & Jonasson, 2005). The development of alternative fuels was aided by a governmental system, in the formation of Svensk Metanol-

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engine. One of the features of Haldex's solution is that it minimizes the losses" (*Kemivärlden* 2003:8, p. 16; translation by the author).

[23] There were several unresolved issues with the AdBlue system, according to the journal article: "AdBlue is [...] likely to cost at least as much as diesel and because the engines technically will work even without the additive, it requires no great imagination to suspect that cheating can become common. But then the NO_x levels become catastrophically high. [...] There are further complications in the future AdBlue technology. The solution is for instance highly crystallizing when in contact with air. It not only makes refuelling "gooey", but also compromises the normal shut-down systems that exist today on the refuelling nozzles such as diesel. Furthermore, Ad Blue is corrosive, requiring special materials in nozzles, filler pipes and tanks. No one wants to increase the risk of spill, which is already a problem when fuelling with normal open tanks. Finally, AdBlue has a freezing point at minus eleven degrees, which requires special heating especially in our latitudes" (*Transport idag* 2004:5, p. 8; translation by the author).

utveckling in 1975 (later Svensk Drivmedelsteknik). The development of Swedish methanol engines by Volvo and Saab-Scania was commissioned by Swedish Drivmedelsteknik. The articles of these two research projects cite techno-economic obstacles that had to be overcome for a rational use of a methanol driven motor, for instance its susceptibility to hot sparks that can trigger explosions (*Ny Teknik* 1982:4, p. 4). Attempts to enable a domestic production of alternative fuels were also made. Studsvik Energiteknik developed a method to produce methanol from biomass or peat (*Ny Teknik* 1983:35, p. 8). Other alternative fuels, such as ethanol, rape seed methyl ester (RME) and natural gas became more attractive than methanol during the 1990s (Sandén & Jonasson, 2005). Some innovations were directed to develop rational production methods of RME, methane gas and ethanol. RME Oilseed Processing AB developed a movable facility to produce RME, anticipating it to replace petroleum diesel (*Kemisk Tidskrift* 1993:9, p. 10; *Ny Teknik* 1993:34, p. 28). An obstacle to the use of alternative fuels was that motors had to be specially adapted. As part of a bigger project aimed to enable biofuels in diesel driven vehicles, Svensk Etanolkemi AB developed a mixed fuel "Etamix" that did not require motor adaption (*Verkstäderna* 1994:6, p. 6). On the motor-side Saab Automobile developed several motors which adjusted automatically to different fuels (*Ny Teknik* 1991:21, p. 5). Volvo was in the beginning of the 2000s developing a truck adapted for the alternative bio-fuel dimethyleter (DME) whose combustion permits low emissions of NO_x and particles (*Ny Teknik* 2002:40, p. 4; 2005:18, p. 4).

6.4.3.3 Electric and hybrid electric cars

A set of stronger incentives to eliminate obstacles to the diffusion or exploitation of a new technology, have characterized the development of electric and hybrid automotive vehicles. Much effort has been aimed at reducing automotive emissions and increase fuel efficiency. The development of hybrid and electric cars and trucks, and the complementary development of automotive engines, batteries and battery stations is a part of the development of more fuel efficient and environmentally friendly cars and transport vehicles. The increased oil, fuel and energy prices in the 1970s forced the automotive industry to concentrate efforts in this direction. Costumer-demand, environmental awareness and sharpened legislation has since then also driven technological development in this direction (Elsässer, 1995). The development of hybrid and electric cars have prompted other complementary innovations. The difficulties in developing sufficiently light and energy-dense batteries with sufficient life length have been salient critical problems that have hampered the commercialization of electric and hybrid cars for decades. Early electric cars and batteries were developed during the 1970s, for use in postal services. One such example is the well-known electric car "Tjorven" produced by Kalmar Verkstad AB in 1969-1970 and used in the Swedish postal services. In the end of the 1970s, Saab-Scania, AGA Innovation AB and the Swedish Post Office developed an electric car with improved battery capacity and driving range (*Verkstäderna* 1977:4, p. 34; 1977:12, p. 39). Svenska Utvecklings AB developed a nickel-iron battery for electric cars with increased energy density to enable increased driving range (*Transport Teknik* 1979:10, p. 312). The battery was used in the development of an electric car developed by Svensk Elektro Transport AB for Televerket (*Transport Teknik* 1979:10, p. 312). Several development projects of new batteries and electric cars were also carried out in the late 1980s and the beginning of the 1990s, all of which were targeting the core techno-economic obstacle of limited life lengths and limited driving range. In the beginning of the 1990s there were several public and private actors promoting the development of electric cars, e.g. SEFOS (Fogelberg, 2000, p. 116). A project to develop electric cars was initiated, involving Gothenburg Municipality, Vattenfall and ABB, who had developed a sodium-sulphur battery (see Fogelberg, 2000, pp. 113-145 for a detailed account of the electric car project). ABB's sodium-sulphur battery was given much attention as it was thought that it could mean a breakthrough for the electric car. It had an energy-density four times higher than the best lead batteries and enabled increased driving range (Ny Teknik 1988:32, p. 5; *Verkstäderna* 1990:10, pp. 75-76; 1992:6-7, pp. 56-58; *Teknik i Transport* 1990:7, p. 36; 1990:7, p. 41). The Institute for Microelectronics (Institutet för Mikroelektronik) was developing a new battery using the oxidation of iron to enable increased driving range and, in particular, less heavy batteries. Apart from insufficient life length the innovation aimed to overcome the problem of weight and bulkiness in earlier batteries (*Kemisk Tidskrift* 1989:4, pp. 46-47). Nordiska Elfordon developed an electric car that achieved increased driving range by mounting the battery charger in the car and recharge the batteries when the car is parked (*Elteknik* 1989:5, pp. 16-17). Clean Air Technologies developed an electric car with a range of 100 kilometers (*Elteknik* 1989:21, p. 11; 1989:22, p. 7). Catella Generics launched a charging station system in 1992 providing another solution for the limited driving range (*Ny Teknik* 1993:22, p. 5).[24]

[24] "People say that the delivery vehicles is something that electric cars will never be used for, says Mats Pellbäck. The driving distance per day is too long and the breaks too short.

Hybrid electric cars have emerged as an alternative, where electrical cars were non-viable. Like electric cars, the development of hybrid cars required overcoming obstacles. The high speed generator (HSG) project was initiated at the Royal Institute of Technology in 1986, resulting in a so-called series hybrid: the combustion engine (gas turbine) drives a generator that charges a battery. The electric motor is driven by the electric energy generated (*Verkstäderna* 1997:11, p. 57). The problem solved by HSG was the problem of adapting the generator to the high speed of gas turbines as compared with electric turbines.[25] HSG was used in Volvo's Environment Concept Car, a prototype hybrid car, developed as a step towards commercial application of hybrid technology (*Energi & Miljö* 1993:10, p. 10). Another example is Solon AB that developed a series hybrid electric car with nickel-cadmium batteries, which enabled a driving range of 600 to 700 kilometres (*Verkstäderna* 1994:5, pp. 10-12).

Both Volvo Lastvagnar and Scania were developing hybrid technologies for heavy trucks, towards the end of the period studied. Effpower developed batteries to solve vehicle manufacturers' problems of batteries for hybrid vehicles. The breakthrough of the hybrid vehicles was hampered by the higher costs relative to gas or diesel fuelled vehicles. Effpower saw a market for batteries with longer life length than previous batteries (*Ny Teknik* 2003:41, pp. 12-13; 2006:11, pp. 4-5; 2006:17, p. 8; *Verkstäderna* 2006:5, p. 47).[26] Effpower's battery was used in Volvo Lastvagnar's electric hybrid system for heavy vehicles (*Ny Teknik* 2006:15-16, pp. 4-5; *Transport idag* 2006:5, p. 29).

The batteries of the electric car is the weakest point. Today's batteries have low capacity, and the loading times are long. [---] Fast charge is necessary for pure electric cars to break through, says Mats Pellbäck. Then you can drive much longer distances in a day" (*Ny Teknik* 1993:22, p. 5; translation by the author).

[25] The problem was solved with new materials and improved calculation methods (*Energi & Miljö* 1993:10, p. 10).

[26] In one of the articles the development is described as follows: "- We can solve vehicle manufacturers' problems of batteries for hybrid vehicles. Our batteries offer high power per kg and can handle many ups and discharges. They can be manufactured in large volumes at a good price, says CEO Mark Sigvardsson. [---] The [...] company has developed a completely new type of bipolar high power batteries based on lead-acid. Such batteries have certainly been around long, but they have a short life because they are prone to leakage and corrosion. These problems Effpower claims to have solved" (*Ny Teknik* 2003:41, pp. 12-3; translation by the author).

6.4.4 Biotechnology and medical applications

As a whole, innovations in the community centered on pharmaceuticals, medical equipment and health care services were not to a large extent developed in immediate response to technological imbalances. However, there are examples of parts of the medical and biotechnology development block in which the advancement of micro-electronics and biotechnology have evolved by way of the solution of critical problems.

X-ray radiation is one of those cases. After X-ray radiation had been discovered to have harmful effects on living tissue, some X-ray innovations launched during the 1970s and 1980s were developed to decrease the radiation dosage. In 1972 Siemens-Elema started development of new carbon laminate based X-ray tables to solve technical problems with the previously used phenolic resin panels, enabling decreased X-ray dosage.[27] Micro-electronics became instrumental in the development of X-ray equipment. Innova Electronics went at the problem with poorly tuned radiation equipment, which increased the risk of radiation (*Elteknik* 1983:12, pp. 30-33). Bild-system's equipment used an electronic filter developed by the American TV broadcasting network CBS that enabled better X-ray images, which in turn enabled less radiation dosage to obtain qualitative images (*Ny Teknik* 1980:47, pp. 14-15). In 1980 Siemens Elema launched a mobile micro-computer based X-ray equipment that likewise was aimed to decrease the necessary X-ray dosage (*Modern Elektronik* 1980:11, pp. 11, 36). Later X-ray equipment innovations (for instance X-ray spectroscopes) have been brought about by advances in e.g. particle physics.

Pharmaceutical development and chemical analysis has during the period studied been characterised by a sequence of technological imbalances. According to Nightingale (2000) and Nightingale & Mahdi (2006), there were three main imbalances in the development of pharmaceuticals. One of the main imbalances was the slow screening of molecules, which was overcome by the introduction of throughput screening in the 1990s. This created a new imbalance in the synthesis of chemicals. The pharmaceutical companies could not develop new interesting substances at a sufficiently

[27] "Up until 1972 the production of X-ray tables used phenolic resin panels in the table. The problem with these discs was that they absorbed quite large amounts of X-rays, which meant that you had to increase the dose X-rays. This was something you wanted to avoid, high doses of X-rays is not good for the patient or the personnel working with the equipment. [---] Within Siemens-Elema they decided to do something about the problem" (*Plastforum Scandinavia* 1981:4, pp. 90-93; translation by the author).

fast rate and were therefore deploying resources into finding automated processes for chemical synthesis. One Swedish example was Pyrosequencing that developed a process for DNA sequencing based on a new method developed at the Royal Institute of Technology (*Kemivärlden* 1999:6, p. 15; 2002:2, p. 16; *Ny Teknik* 1999:37, p. 9; 2000:39, p. 20). Another firm, Personal Chemistry, developed a microwave oven for organic synthesis (*Ny Teknik* 1999:41, p. 12). Cellectricon's innovations attacked similar critical problems in drug screening and development of new drug candidates. Cellectricon's Dynaflow process automated the drug screening process by way of a "micro-shower" for cells (*Ny Teknik* 2002:39, p. 8; 2003:16, p. 7; 2003:43, p. 12). A similar case was proteomics, the study of proteins. Proteomics grew as a potent field in identifying drug targets and biomarkers. There were however techno-economic problems that involved the separation, quantification and validation of proteins and drug targets. Nanoxis (*Ny Teknik* 2003:39, p. 11; 2004:21, p. 8) and Affibody (*Ny Teknik* 2000:40, p. 18) were examples of firms that responded to these obstacles.

The introduction of automated synthesis of large amounts of chemicals however also created a new imbalance in the inability of firms to handle the large amounts of data. During the second half of the period the advances made in computer programming could be exploited to solve technical problems in areas such as pharmaceutical production and genetic engineering. Visual Bioinformatics responded to the problem of handling large amounts of experimental data and developed an analysis program to analyze and visualize the data (*Ny Teknik* 2000:40, p. 6). Another example is Sidec Technologies that developed a method to process large amounts of information, applied in the pharmaceutical industry (*Ny Teknik* 2003:23, p. 8).

6.4.5 The Forestry sector

Some problem complexes were characterized by a strong negative transformation pressure during the structural crisis of the 1970s. The severe situation that emerged in the forestry sector has already been described in chapter 4. Problems in the forestry sector became severe when an acute wood shortage broke out during the 1970s when both production shrank and prices were kept low despite high demand. In 1974 the yearly deforestation level of the forestry industry reached the maximum level allowed by Swedish legislation (Josefsson, 1985, p. 241). These conditions influenced a number of forestry machinery innovations aimed to enable better wood usage per tree felled. These innovations can be understood as a block of innovations aimed to make profitable culling and handling of wood and to eliminate obstacles hindering the introduction of rational production methods, such as whole tree deforestation.

The development of whole tree deforestation methods and machinery, for instance Kiruna Truck's (1975) or Elektro-Diesel's tree fellers were aimed to make possible increased volumes. Enabling increased wood volume per tree felled was naturally an important element in forestry innovation in general. Machinery was also developed to make profitable the handling of forest fuel (Sikob, 1986). Several innovations were aimed to overcome the unprofitability in culling of forests. AB Dala Gummi launched a forwarder in 1975 that was aiming to overcome obstacles to the development of rational culling systems. One such risk was that the machinery destroyed the remaining tree roots (*Ny Teknik* 1975:30, p. 6).[28] When launching a recently developed forest machine labelled "Kockums 81-11", Kockums claimed "to have the solution to one of the biggest problems of forestry - to attain profitability in early weeding" (*Svensk Trävaru- och Pappersmassetidning* 1982:11, p. 729; translation by the author). At the time, most of all culling was carried manually, i.e. with chain saws. This was considered a costly and cumbersome work with low profitability. The machine was adapted to become small and flexible (*Svensk Trävaru- och Pappersmassetidning* 1982:11, p. 729; *Sågverken* 1982:10, pp. 59-61). Kockums also launched a stump cleanser that was aimed to make profitable the collection of stumps (*Ny Teknik* 1979:12, pp. 8-9).

Similarly, unprofitability in dealing with cull wood has also motivated new methods to transform wood to pulp and raw material for energy production. ASSI developed and launched an equipment for the compression of pine tops aimed to make profitable the exploitation of pine tops.[29]

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[28]"A forwarder is a type of machine that is used to transport felled trees from the forest to the storage sites. A request from the forest industry is to develop rational culling systems, and, to the extent possible, to use machines in these [systems]. The risk is, however, that the machinery, if fitted with bands, destroy the remaining tree roots as they go through the woods. [---] In order to reduce the negative impact on tree root systems in forest machines used for sorting data, the department of Forest Engineering at Skogshögskolan in Garpenberg, and rubber manufacturer AB Dala Gummi, have developed a new type of caterpillar for the bogie to a so-called forwarder. The belts are made of steel and rubber. [---] Tests show that rubber bands steel is gentler than steel straps" (*Ny Teknik* 1975:30, p. 6; translation by the author).

[29]"So far it has not been profitable to exploit pine tops and other small timber because it is so bulky. It has not been possible to use the vehicles carrying capacity. Now it is possible,

Elektro-Diesel was developing a machine for the unrooting of trees, aiming to overcome obstacles to the use of whole tree deforestation methods. Stumps had been shown to be useful sources of raw materials. Elektro-Diesel's deforestation machine enabled an increase in the volume of wood extracted (*Sågverken* 1975:5, pp. 397-399; 1975:10, pp. 721, 727). Elektro-Diesel also developed a tree feller for the unrooting of large trees.[30]

6.4.6 Offshore markets

The community surrounding shipbuilding and military defence was largely reflecting strong traditional industrial linkages. However, diversifying from the crisis struck shipbuilding industry, some innovations were aiming to solve problems in the emerging offshore markets in the North Sea. The search for oil in the North Sea started during the late 1960s after oil and gas deposits had been found outside the coasts of the Netherlands and the UK. A wide range of new products were necessary to solve the problems involved in the exploitation of these resources. In addition, this market came to be the target of many diversifications. Firms facing shrinking markets in fields as diverse as shipbuilding, pulp and paper and nuclear power came to look towards the emerging offshore market.[31]

Problems in drilling and extraction of petroleum were brought about by the harsh climate of the North Sea and the incurred costs and difficulties from deep sea drilling. Due to these difficulties, Kockums developed a submarine system that was weather independent (*Ny Teknik* 1975:18, p. 8; *Verkstäderna* 1975:9, p. 43; *Transport Teknik* 1976:6, p. 181; *Automation* 1977:7, pp. 36-37).[32] The exploitation of oil and gas deposits in the

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thanks to the compression equipment developed precisely for meager timber. Each bundle of wood loaded compressed by two flaps attached to the telescopic struts on the vehicle. The twigs on the timber break and you get a compact load" (*Ny Teknik* 1981.8, p. 18; translation by the author).

[30] "Tree feller that unroots large trees with stump and roots is now tested in production outside Kalix in Norrbotten. 25 per cent of the total volume of a tree is in the stump and the roots – and it these volumes that the 'wood starving' industry is searching for" (*Ny Teknik* 1979:40, p. 32; translation by the author).

[31] In addition to innovations in the SWINNO database it may be mentioned that, Asea-Atom diversified into this field. Due to a referendum and the parliament's decision to close down nuclear power plants in the long run, the future of nuclear power was considered uncertain. Facing these uncertainties Asea-Atom decided to invest in a programme for offshore activities, becoming Asea Oil and Gas (Dahlquist, 2011).

[32] Surface ships were very weather sensitive. The North Sea being is one of the most

North Sea would not have been possible without the development of floating platforms. Götaverken Arendal Cityvarvet developed *Safe Astoria*, a semi-submersible platform for offshore drilling, which was the company's step into the offshore market (*Verkstäderna* 1978:12, pp. 60-61). The platform was the worlds' first of its kind, and other innovations followed (*Ny Teknik* 1981:13, p. 28; *Ny Teknik* 1997:17, pp. 28-29; *Ny Teknik* 1984:20, p. 62).

Another related problem was the underwater maintenance of oil rigs. This problem was the target of innovations developing underwater robots and underwater vehicles. For instance, Sutec (Scandinavian Underwater Technology) developed the "Sea dog" and "Sea Owl", underwater vehicles (*Verkstäderna* 1982:1, p. 42; *Ny Teknik* 1983:3, p. 4; 1984:1, p. 12).[33]

As was pointed out in chapter 5, both Kockums and Götaverken diversified into offshore during the crisis of the shipbuilding industry. Commissioned by the Defence Material Administration (Försvarets Materielverk), Kockums developed an underwater vehicle that also meant a step into underwater technology and the off-shore market (*Automation* 1977:7, pp. 36-37). The aforementioned capsizing accident (see page 169) of the Norwegian rig Alexander Kielland in 1980 moreover induced Kockums to develop a hydrophone measuring equipment (*Ny Teknik* 1981:40, p. 32).

Other firms were also solving problems for the offshore markets while responding to the structural crisis. MoDoChemetics, active in the pulp industry, found a new application of an old technology when facing adversities in their traditional markets. The purification of natural gas encountered problems in the North Sea (see footnote), and an old technology for the purification of gas in distillation columns appeared to solve the problem (*Ny Teknik* 1983:13, p. 3).[34]

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difficult with often severe storms and very rough sea with often 20 meters high waves. Here a submarine system with surface vessels could not used more than approximately 100 days a year. The corresponding figure for the new system was expected to be about 300 days (*Ny Teknik* 1975:18, p. 8; *Verkstäderna* 1975:9, p. 43; *Transport Teknik* 1976:6, p. 181; *Automation* 1977:7, pp. 36-37).

[33]The long cables were an obstacle to the capacity and range of underwater robots. A later innovation aimed to construct an underwater vehicle, controlled completely without cable (*Ny Teknik* 1986:12, p. 36).

[34]"The purification of the gas occurs in distillation columns that are similar to those used in the pulp industry. Normally they stand up - on land or attached to the seabed. At the intermediate bottom of the columns, the gas is supposed to meet liquids that cleanse it from water. The problem occurs if the platform is rocking, the liquid sloshes around in the column and the water remains in the gas. But that's the problem MoDo Chemetics

6.4.7 Construction, mining, wood and metal products

The community centered on construction, mining, wood and metal products may primarily be interpreted as reflecting strong production linkages between these industries. A large number of innovations in this community can be characterized as problem-solving. The typical problem-solving innovations were for the most part aimed to solve idiosyncratic problems to firms or industries.

Problem-solving innovations in this community however also pertained to overcoming problems in the work environment, in particular during the 1970s and 1980s. These organizational problems were related to the removal of asbestos, the dampening and removal of industrial noise and vibrations, reduction of toxic welding fumes and the reduction of occupational injuries in the wood and mining industries in particular. These problems and some of these innovations are discussed in chapter 4 and chapter 5.

When the adjustment to these organizational problems has required new production processes and equipment, innovation activity has assumed a more systemic character, i.e. involving a broader set of actors, products and industries. This may be argued to have been the case as regards some of the long standing problems in the work-environment. A case in point is the broad adjustment necessary to reduce and handle the toxic welding fumes (see section 4.4.2.2 for a brief discussion). Another case, not previously discussed, was the innovation activity directed to solve the problem with industrial noise and vibrations, which span industrial process machinery innovations to sound dampening rubber innovations. Dealing with occupational noise has required a broad set of innovations, from isolation techniques and protection devices to techniques for the reduction of vibrations. The problem of occupational noise among other work-environment problems was given increased attention from the late 1960s, when the Swedish Trade Union Confederation made a work-environment poll among its members (Thörnqvist, 2005, pp. 278-289). The innovation responses have pertained both to reducing the adverse effects of occupational noise and to reducing the actual occupational noise. The first type of response can be exempli-

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solved with a new construction of intermediate bottoms. The farther north you go in the newly opened oil fields in the North Sea, the greater the problems. The result is, among others, ice formations that plug the pipelines. MoDo Chemetics already has another bottom construction of the column to handle pulp industry for purification of poisonous gases. - Our bottom construction is radically different from that which is common on oil rigs. We have developed it to invest in offshore market when investments in the pulp industry declined, says Karl-Johan Kandolin" (*Ny Teknik* 1983:13, p. 3; translation by the author).

fied with Standard Radio & Telefon AB's hearing protection device with a built-in microphone (*Verkstäderna* 1979:16, p. 48; *Sågverken* 1981:8, pp. 53-55; *Ny Teknik* 1979:42, p. 8). Bofors AB, in collaboration with Rikard Johansson AB developed a grinding machine with the purpose of lowering noise. The solution was to isolate the machine into a specific area of the premises and an operating system which allowed distance control from another room. Noise and dust exposure could thus be avoided (*Verkstäderna* 1977:3, pp. 30-32). Waco AB developed a noise cabin that worked similarly by isolating the sound from the machine (*Sågverken* 1976:7, p. 571). The second strategy has sometimes required more substantial changes in production and materials, and the overcoming of technical obstacles. In some cases materials and tools were necessary to replace. Sandvik e.g. developed a circle saw blade which through new construction principles produced lower noise levels (*Sågverken* 1974:3, p. 213). As the reductions of occupational noise, were still at the end of the period considered unsatisfactory, the problem of reducing noise may be described as a critical problem. In 2006, an article stated: "The high noise level as well as the vibrations are known problems in all cutting processing and it has been considered to be impossible to remove" (*Ny Teknik* 2006:49 "Automation", p. 12; translation by the author). The Swedish firm Acticut therefore developed a technology that used "counter-vibrations" to nullify the vibrations.

6.4.8 Packaging, cooling equipment and food and beverages

A development block centered on the foodstuff industry has since the postwar era been a salient part of the Swedish manufacturing industry. Åkerlund & Rausing launched Tetra Pak in 1951, forming the basis of the new company with the same name. Åkerlund & Rausing and Tetra Pak not only developed plastic innovations but also machinery and automation products that were complementary to the packaging innovations.

A large number of innovations in this development block were centered on problems emerging in the introduction of freezing and cooling technologies. In particular innovations were aimed to eliminate obstacles to the wider introduction of frozen food technology. The first quick-frozen food were sold to the public in the US already in 1930 (Bäckström et al., 1992, p. 165). In the 1950s frozen food was introduced on the Swedish market. The introduction of frozen food required packaging innovations, plastic innovations, freezing methods and equipment (Bäckström et al., 1992;

Beckeman & Olsson, 2005). Åkerlund & Rausing and Esselte Pac were developing frozen food packaging innovations in the beginning of the 1950s, solving leakage problems in the distribution of frozen food (Beckeman & Olsson, 2005, p. 9). Some firms were introducing quick-frozen foodstuff innovations in the 1970s, e.g. quick-frozen meat launched by KF in 1970 (*Livsmedelsteknik* 1970:3, p. 145) and quick frozen salads launched by Findus in 1978 (*Livsmedelsteknik* 1978:2, p. 92). Scan had developed several quick-frozen meat and frozen half-baked dishes towards the end of the 1970s. A major innovation "Pellofreeze" was launched in 1971 by a central actor in this field, Frigoscandia (Wallmark & McQueen, 1988, 1991). It was developed against the background of the introduction of techniques for Individual Quick Freezing in the beginning of the 1960s. The freezing technology was necessary for certain products to be sold in frozen form. Frigoscandia had previously launched an innovation "Flo-Freeze" that replaced the freezing of peas and other vegetables of uniform size (see also Wallmark & McQueen 1988, 1991). However, there were technical obstacles to the introduction of quick-freezing as regarded liquids or products such as whipped cream, spinache and some sorts of meat.[35] Pellofreeze was developed to bridge this gap (*Livsmedelsteknik* 1971:1, p. 36; 1977:1, pp. 24-25; *Ny Teknik* 1971:2, p. 5). Other problems in the use of quick-freezing technologies pertained to fact that bacteria and other microorganisms thrive in foods being thawed. This problem was the source of another innovation launched by Frigoscandia in 1976 (*Ny Teknik* 1976:35, p. 14). Mikrovågsapplikation AB's method used microwave technology for fast industrial thawing of quick-frozen meat (*Livsmedelsteknik* 1982:3, pp. 116-118). Frigoscandia continued the development of equipment for quick-freezing, launching several other freezers, e.g. Cryofreeze (*Livsmedelsteknik* 1981:6, p. 296) and GyroCompact (*Livsmedelsteknik* 1984:1/2, p. 43) that aimed to make the freezing process quicker and to attain better hygiene.

Frozen food also meant high requirements for distribution and storage. One innovation was aiming to overcome difficulties in the co-distribution of refrigerated goods with different temperature requirements (*Livsmedelsteknik* 1979:1, p. 41; *Kemisk Tidskrift* 1979:2, p. 15).[36] AGA Gas Division's cool transport system was aimed to enable transport of tempera-

[35] Such products had up to that point been sold in frozen blocks (*Livsmedelsteknik* 1977:1, pp. 24-25).

[36] The Food Act of 1971 introduced temperature restrictions that made such co-distribution difficult. The innovation was developed by AB Smulan in collaboration with Packforsk.

ture sensitive perishables in standard trucks and trailers (*Livsmedelsteknik* 1977:6, p. 304).

6.4.9 The pulp and paper industry

The alleviation of the paper and pulp industry's environmental problems has involved not only new production processes, but also new paper and pulp machinery, measuring apparatus and new chemicals. As has been mentioned earlier (see page 216), Swedish firms have been pioneers in producing biofuel from residue from the pulp and paper industry. These innovations have both aimed to solve environmental problems and to reduce production bottlenecks, such as the costly recovery boilers. Another set of innovations were developed to replace traditional chlorine bleaching processes.

The first initiatives in the pulp and paper industry to deal with emissions and pollution took place in the beginning of the 20th century (Söderholm, 2009). With the Environmental Protection Act of 1969, efforts were directed towards emissions and developing new processes for bleaching of pulp residue.

During the 1970s oxygen bleaching processes were developed in Sweden, e.g. by MoDo and Kamyr (*Kemisk Tidskrift* 1976:7-8, p. 14; 1976:11, p. 18). Main chlorine free alternatives were oxygen bleaching and chlorine dioxide bleaching. In Sweden, several firms developed such processes during the 1980s.

From the end of the 1980s the industrial emissions of absorbable organic halogens (AOX) were regulated, which meant a push into technology development. As a response to environmental regulations of AOX, Eka Nobel developed its Lignox method, a chlorine free bleaching process, based instead on hydrogen peroxide (*Kemisk Tidskrift* 1990:5, p. 11; *Svensk Papperstidning* 1990:9, p. 7; 1990:18, p. 24-26; 1991:10, p. 32-33, 35-36, 39-40). Using the Lignox method Aspa bruk also launched a new class of environmentally friendly chlorine free pulp "EF 70" (*Svensk Papperstidning* 1990:18, pp. 24-26). Environmental legislation also induced MoDo to develop a bleaching process called "Prenox" (*Ny Teknik* 1987:21, p. 4; 1989:21, p. 6).

Other problems however emerged in the new environmentally friendly processes. For instance, chlorine dioxide bleaching proved to give other emissions in the form of toxic chlorine ions. To reduce these problems Anox developed a new process employing previously unknown bacteria to purify the waste water (*Ny Teknik* 1990:13, p. 32). Chlorine free bleaching methods also were unable to tackle technical problems caused by hexenuronic acid, something that spurred research internationally and Kvaerner Pulping to develop a new method (*Svensk Papperstidning* 2002:4, p. 22).

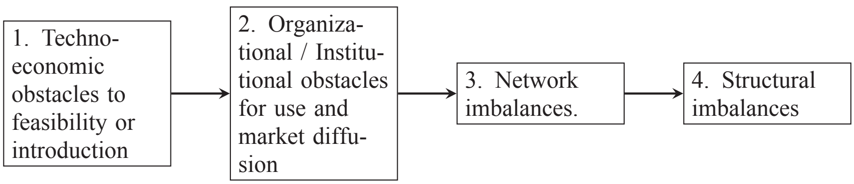
6.4.10 Summary: a typology of imbalances

Summarizing the above-given examples, an observation is that many of the development blocks found can be broadly understood as related to two macro-economic problem complexes: imbalances emerging in the ICT technology shift, and imbalances emerging in the attempts to deal with the adverse environmental and societal effects of oil based technologies and production systems. The former imbalances have for the most part been driven by a positive transformation pressure. The latter for the most part by a negative transformation pressure.

A second observation is that the imbalances found to spur innovations have been somewhat different in character. A summary of the technological imbalances that have motivated innovation activity can be found in Table 6.10. Some imbalances have effectively hampered the market introduction of a new technology. These types of imbalances have concerned the development blocks centered on replacing fossil fuels, oil dependency and the early introduction of emission control technology. The unsatisfactory battery life length and too high weight for electric cars is a particularly clear example. Some imbalances have hampered the wider use of a new technology, e.g. the use of quick-frozen foods. Other imbalances, which one may refer to as *network* imbalances or systemic imbalances, have pertained to the alignment of capacities of components and technologies in a larger system of interdependencies. The imbalances found in the expanding telecommunications and Internet were of this type, but also other innovations that were adapting to the requirements of computers and telecommunication networks. Some such examples were found among the electricity distribution innovations. Moreover, imbalances in the development of pharmaceuticals and drugs, may be considered to have been systemic in character, requiring attacks on technological bottlenecks in various parts of the process of drug development.

A final set of innovations have responded to imbalances, of a more structural character, i.e. requiring changes in the established ways of production, distribution or transportation. Innovations in forestry responded to a fundamental unprofitability and obstacles to the introduction and use of rational production methods. Other responses have taken the shape of necessary *structural adjustments* to new environmental and occupational standards, laws or requirements. Such innovations were found in the community centered on construction and engineering industries and the pulp and paper industry. In these cases the "imbalance" lies between the institutional or societal requirements and the technologically possible performance. A large number of environmental innovations have been driven by such regulations (see also the discussion in chapter 5 of chemical innovations attempting to replace freons and halogens).

Figure 6.6: A sequence of widening imbalances in the evolution of a development block.



These observations underline a life-cycle perspective in the evolution of development blocks. Development blocks may be said to evolve by way of widening imbalances, from obstacles to the introduction of new technologies, to the emergence of structural imbalances (see Figure 6.6). Structural imbalances in turn have induced the emergence of new development blocks, struggling with their own obstacles. Clearly, the structural problems of the oil-based Fordist production regime have given rise to new development blocks around renewable technologies, emission control technologies and electric cars that have faced their own imbalances.

Table 6.10: Innovations centered on solving imbalances, 1970-2007.

Development block	Contained in community (no)	Critical problems (summary)	Type of imbalances
Automated guided vehicles	3	Insufficient capacities of control systems	Introduction and use
Solar power (solar collectors and solar cells)	9 i.a.	Limited sun exposure e.g., cost structure	Introduction
Nuclear power	9	Security	Introduction
Biomass	9 i.a.		Introduction
Heat pumps	9 i.a.	Technical construction problems	Introduction
Emission control technology	4	Availability of unleaded fuels, Technical problems in catalytic converters	Introduction and use
Electric and hybrid electric cars	4	Weight and energy density of batteries	Introduction
Laminate for electronic components	3	Under-etching	Introduction and use
Quick-frozen food	2	E.g. bacteria in thawing, temperature in distribution	Use
Speed control of AC motors	9	Speed control	Use
Offshore exploitation of resources in the North Sea	8	Rough climate, Maintenance of oil rigs	Use
Secure payment and secure identification	3	Security issues in Internet networks	Introduction/Network
Telecommunication and Internet networks	3	Capacity requirements of network standards	Network
Pharmaceuticals and drug screening	5	E.g. slow drug screening, incapacity to deal with vast amounts of data	Network
Forestry deforestation methods	6	Unprofitability, obstacles to rational production methods	Structural
Occupational noise	7	Technical difficulties in reducing vibrations	Structural
Chlorine free bleaching processes	1	Replacement of chlorine	Structural

6.5 Conclusions

This chapter has aimed to describe the influence of intersectoral factors on innovation activity. The main vehicle of this analysis has been the study of patterns of supply and use of innovation. The development during the period has demonstrated important structural changes in the supply and use of innovation. A broader shift in the user sectors can be noticed. By and large the change in users of innovation could be described as a shift from users in traditional industry and transportation services, towards the production of motor vehicles (SNI 34), users within the ICT sectors (SNI 30-33, 64 and 72), health care services (SNI 85) and other business services (R&D and consultancy, SNI 73-74). A shift towards final consumers can also be observed, primarily accounted for by the increase in telecommunications and software innovations.

This chapter has also introduced the patterns of intersectoral flows of innovation and has discussed intersectoral interdependencies as driving forces of innovation. Using statistical analysis ten groups of closely related industries - communities - were found. The communities were suggested to be indicative of plausible development blocks. The statistical and qualitative analysis revealed that several of these communities were focused on resolving technological imbalances, either under a fundamentally negative transformation pressure, as in the forestry industry during and following the structural crisis of the 1970s, or positive transformation pressure, as in the telecommunications industries during the 1990s. In these cases the innovations involved were parts of smaller or broader development blocks centered on the exploitation of new technologies or the overcoming of technological imbalances. Several sets of activities in which innovation has aimed to solve imbalances and supply complementary factors, were particularly found in the communities surrounding Foodstuff, ICT, Automotive vehicles, Electricity, Forestry, and Pulp and paper. A set of innovations surrounded renewable energy technologies, strongly evolving by way of solving obstacles. These development blocks were in part related to the Electricity community but were broader than the boundaries set by industry classifications. The community surrounding Medical equipment was not centered on the solution of problems, but rather driven by the emergence of opportunities through micro-electronics and biotechnology (see also chapter 4). However, within and related to this community there were innovations responding to sequences of imbalances in the advancement of diagnostics. The community centered on Construction was to a large extent problem-solving. This case was not a typical development block, but reflected strong interdependencies in the supply chain that have been important channels to problem-solving activities.

Finally, among the communities found, there were two that primarily reflected production linkages, rather than the dynamics of a development block. The community centered on shipbuilding and military defence rather reflected strong industrial production linkages between aircraft, weapons, shipbuilding and military defence, rather than innovations solving technological imbalances.[37]

The character of imbalances that have motivated innovation activity has varied with the stage of the development blocks. In formative phases, obstacles have limited the introduction of a technology. An obvious case is the electric car, which still has not overcome the fundamental difficulties of attaining sufficient driving ranges. Some obstacles have limited production or wider diffusion of a new technology. In larger dynamic development blocks, imbalances have concerned the expansion of complex networks. Finally, imbalances of a structural character have induced the introduction of new production methods (the forestry sector) or entirely new development blocks.

The notion of downstream exploitation of basic technologies obtains support when analysing the ICT revolution. The major imbalance to the wider exploitation of micro-electronics was solved with the arrival of the micro-processor. While there were examples of innovations being developed to solve techno-economic obstacles, the majority of ICT innovations during the first half of the period were exploiting the technological opportunities made possible by basic innovations. By contrast, the surge in telecommunication and electronic component innovations during the 1990s can to a great extent be explained by innovations attempting to overcome techno-economic obstacles to the deployment of Internet and telecommunications technologies.

[37] The community centered on textiles reflected the self-evident interrelations between suppliers of textile machinery and the textile and clothing industries.

7. Firm-level Determinants in the Third Industrial Revolution

7.1 Introduction

One of the main results of the previous chapters is the observation of two surges in the count of ICT innovations. The first surge took place after the structural crisis of the 1970s and was concentrated to the exploitation of the new microelectronics technologies. The second surge took place during the boom of the 1990s, concentrated to the wider diffusion of Internet and telecommunication technologies. For a full appraisal of the determinants of innovation in the ICT industries it is however necessary to take into consideration the immediate economic conditions and environment of the firms. The aim of this chapter is to examine the micro-economic driving forces in the two waves of ICT innovations observed in chapter 4 and chapter 6. As it were, this chapter examines the micro-basis of the ICT technology shift. Specifically, this chapter studies firms that have developed hardware electronics products. The hardware electronics industry encompasses the following industries: computers and office machinery (SNI 30), electrical apparatus (SNI 31), telecommunication (SNI 32), and electronic equipment (SNI 33).

The main question posed is:

- *What firm-level factors drove the development of hardware electronics innovations?*

The literature on firm-level determinants of innovation typically distinguishes between different dynamics in entrant and incumbent firms. A second strain distinguishes between positive and negative firm-level determinants of innovation among incumbent firms (see below). The main question is therefore answered by posing two sub-questions:

- *What role did the entry of new firms play in the technology shift?*
- *Did positive or negative firm-level factors drive incumbent firms to develop hardware electronics innovations?*

Accordingly, the first issue dealt with in this chapter is to what extent innovations were developed by entrant firms and what factors drove their start-ups during the technology shift process. Start-up firms and new entrepreneurs have been described as pivotal to the evolution of new industries (Schumpeter, 1939; Freeman et al., 1982; Utterback, 1994; Klepper, 1996). This certainly applies to the ICT industries (Fransman, 2002; Krafft, 2004, 2007). Fransman (2002, pp. 41-54) has described the evolution of the international Telecom industry in two phases. Before the 1990s the markets were characterized by few innovators and high entry barriers, despite the deregulations of telecommunication markets in the 1980s in the US, Japan and UK. From the early 1990s there was a rise of new entrants that responded to lowered barriers of entry and changed the mode of competition in the industry. Likewise, Mölleryd (1999) and McKelvey et al. (1997) have shown the increasingly important role played by new entrepreneurs during the IT boom of the 1990s. The first part of this chapter examines the role played by start-ups in the innovation activity of hardware ICT industry in Sweden during the period studied and the origins of the start-ups of these firms.

The second issue is what role incumbent firms played and to what extent incumbent firms have been driven by positive or negative factors at the firm-level. Section 7.3 examines whether innovation is positively or negatively related to the incumbent firm's previous performance by combining quantitative methods (see section 7.3.4) and qualitative methods (see section 7.3.5). Cyert & March (1963) proposed the existence of two types of search behavior: (1) failure-induced search initiated to solve problems and to close the gap between aspiration levels and performance, (2) search for by using slack resources. A third type of search has also been added, which pertain primarily to large firms: institutionalized search (March, 1981) to keep the firm at the competitive frontier. Large firms have, at any point in time, many development projects in their pipelines. The activities of R&D departments or Strategic Planning activities are cases in point.

Following this line of research some scholars have shown that firms tend to respond creatively to negative "performance feedback", i.e. performance that falls short of the firm's aspired level of performance. These studies have been carried out for firm samples in industries, e.g. in high-tech industries (Bolton, 1993), the radio broadcasting industry (Greve, 1998), semiconductor industry (Boeker, 1997), airlines (Audia et al., 2000) and shipbuilding industry (Greve, 2003a,b; Audia & Greve, 2006; Greve, 2007). Some studies have compared nation-wide samples of firms (Hundley et al., 1996) or industry wide samples of firms in e.g Italy (Antonelli, 1989; Antonelli & Scellato, 2011). Other case studies have focused on a small set of firms (Wagner & Ettrich-Schmitt, 2009). This literature provides ample support for the idea of failure induced innovation.

In the view of Penrose (2009 [1959]) organizational excess resources may induce search for new innovations. A strand of literature has investigated the relationship between slack resources and innovation (Nohria & Gulati, 1996; Greve, 2003a; Özcan, 2005; Herold et al., 2006; Wagner & Ettrich-Schmitt, 2009). Slack has been viewed as both creating funds for innovation and as reducing managerial discipline. Nohria & Gulati (1996) suggested an inverted U-shaped relationship between slack and innovation. While some studies have found a positive impact of slack on innovation, the empirical evidence is in general mixed. The second part of the chapter follows the approach of Greve (2003a,b) and similar studies. It focuses on the firm-level determinants of innovations and analyses the quantitative evidence found for an impact of performance and excess resources on innovation activity in a selection of incumbent firms active in the ICT hardware industry. The analysis is focused to firm-level determinants of innovation employing economic data for a selection of innovating firms in the ICT-industry.

In a third part of this chapter, the sample of firms is subjected to a closer study by the use of qualitative accounts of firm history and driving forces of the innovations. This analysis examines the historical settings in which firms have innovated. Previous literature have suggested that response may imply exploring new markets or product technologies or exploiting the firm's resources (March, 1991; Rosenkopf & Nerkar, 2001; Greve, 2007). The "how" of creative response is placed in focus. To organize the descriptions the study takes special interest in whether firms have responded to adversity by way of renewal (exploration) or by focusing their activities towards efficiency or consolidation (exploitation).

7.2 Entrants and incumbents in the electronics industries

As discussed previously, there are two key aspects of driving innovation activity in advancing industries. The first aspect corresponds to Schumpeter Mark I: new actors that enter markets to commercialize new products. The second aspect concerns incumbent firms that react to changes in their economic environment by innovation. In this section I will describe what role these two types of innovation had in the electronics industries.

7.2.1 Firm entry and firm age

Apart from the firm variables used in chapter 5 to assess firm size, the SWINNO database contains data from Statistics Sweden on the start year of the innovating firm. As the raw data from Statistics Sweden has some limitations (e.g. no start year before 1973), the data has been reworked and cross-checked with other sources for the firms launching hardware electronic innovations.[1]

The start years of innovation firms are used here for the purpose of shedding light on market entry in the electronics industries. There were in total 1315 innovations in the hardware electronics, launched by 792 innovating firms. For 1054 innovations the start year of the innovating firm could be identified. In figures 7.1, 7.2, 7.3 and 7.4 the main results are shown. The first figure shows the count of innovations developed by firms less than 10 years from the start year. The figure shows that young entrant firms did not to a large extent launch electronics innovations until the mid-1980s. In the first half of the period (1970-1989), firms younger than 10 years launched 23.9% of the total count of electronics innovations. This is consistent with the description of ICT innovations given in chapter 4. In the early period micro-electronics innovations were developed by large firms (such as Asea) or subsidiaries to large firms (such as Datasaab, which was spun-off from

[1] The data was modified when necessary for firms innovating in industries SNI 30-33. The original data has been cross-checked with company histories and an Internet service provided by "AffärsData" (www.ad.se), which provides full dates backwards and forwards when firm names were registered. Start years for firms entering before 1973 have been added. As a principle, subsidiaries to large corporate groups such as L M Ericsson, Asea or Saab-Scania have given the start year of the corporate group if they were started as part of the corporate group. If they were acquired, the original start year has been used.

Saab). By contrast, during the latter half of the period (1990-2007) the share of young entrant innovating firms was more than half (firms younger than 10 years launched 52.4% of the innovations).

The role of entrant firms appears in a different light when examining the count of entries per year. Figure 7.2 shows the pattern of entry of firms innovating in the hardware electronics industries 1970-2007. Each firm is counted only once. An especially large number of firms entered between 1984 and 1989. The two last figures (Figure 7.3 and 7.4) informs us of two movements in the entry of firms. An increase in the number of firm starts occurs in the mid 1980s, pertaining in particular to the computer and electronic equipment industries. Thus, a wave of entrant firms followed upon the surge of innovations during the structural crisis (1975-1979 and 1980-1984). Firm entry for the other two industries, the telecommunication industry and the electrical apparatus industry, increase slightly during the 1980s. The count of entering firms peak in the window of opportunity between the crisis of the 1990s and the IT bust in 2000. The count of entrant innovators in the telecommunication industry, peaks in 1999-2000. The pattern of entrant telecommunication firms is similar to population wide studies of new technology based firms in Sweden (see e.g Ejermo & Xiao, 2013 that study the period 1991-2007).

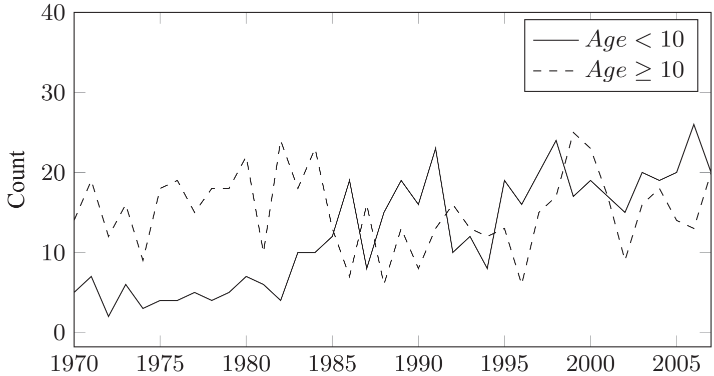
One may note the similarity between the surges in micro-electronics and ICT innovations found in chapter 4 and the timing of entry of innovating firms. It appears that the peaks in the count of entrant firms has occurred at the same time as the innovation counts of ICT innovations have culminated, i.e. roughly in 1983-1984 and 1999-2000.

7.2.2 Origins of innovative entry 1970-2007

Next one may ask what factors drove the entry of innovating firms in the hardware ICT industry. Variables that capture the determinants of entry have not been possible to collect in the SWINNO database. Instead, it is proposed that the origin of entry may be approached by analysing the origin of the first innovation that entrant firms developed. If the innovation drove the entry of the firm, information on the innovation process may be considered to indicate factors behind the firm's entry decision, whether it be the exploitation of a new technology or scientific advances or to solve a generic technological problem.

365 of the firms that entered into hardware electronics were mentioned

Figure 7.1: Count of electronics innovations launched, by firm age, 1970-2007.



Note: For 251 innovations out of 1305, the innovating firm could not be classified according to start year.

Figure 7.2: Number of firms innovating in the electronics sector 1970-2007, by start year 1900-2007. Total count (SNI 30 - 33).

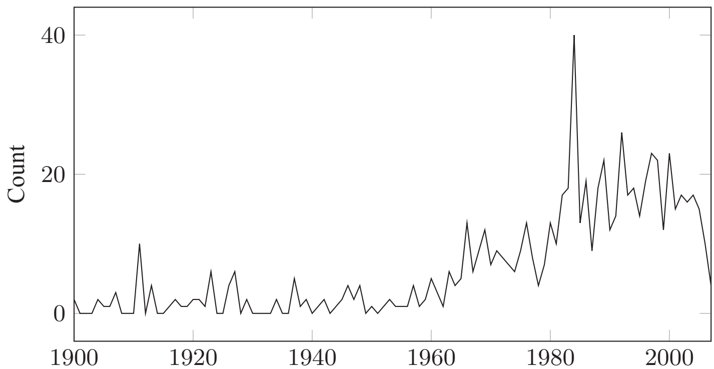


Figure 7.3: Number of firms innovating in the electric apparatus (31) and telecommunication (32) industries 1970-2007, by start year 1900-2007.

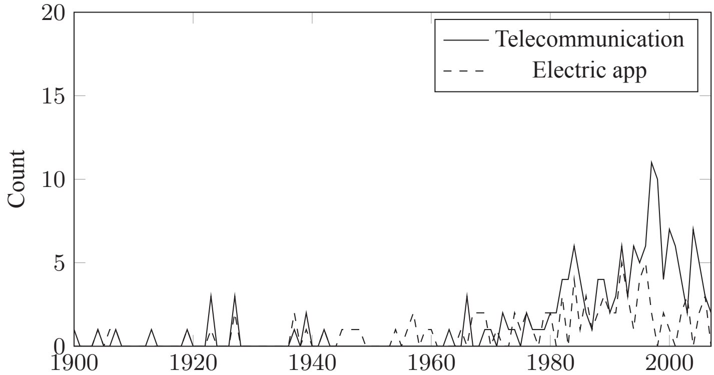


Figure 7.4: Number of firms innovating in the computer (30) and electronic equipment (33) industries 1970-2007, by start year 1900-2007.

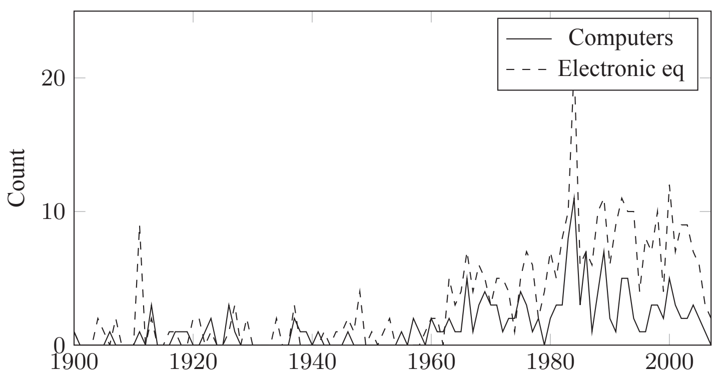
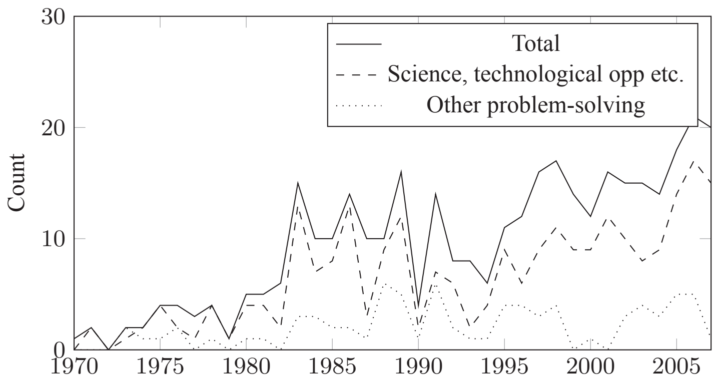


Table 7.1: Origins of first innovation in 365 entrant firms.

	Other problem-solving	New technologies and materials	Technological bottlenecks	Scientific discovery and academic research	Total
1970-1989	31	89	16	22	124
1990-2007	48	122	65	59	241
Total	79	211	81	81	365

Note that that the variables may overlap. The period totals therefore do not equal the row sums.

Figure 7.5: Start-up innovations of entrant firms in hardware electronics (SNI 30 -33). By origin and year of commercialization 1970-2007.



to be firms in which the innovation drove the start-up, or that launched an innovation within five years after firm start. Out of these, 251 start-up innovations could be attributed to either of the following factors: exploitation of new technologies and materials, scientific discovery and academic research, techno-economic obstacles to the introduction of (other) new technologies, or other problems (e.g. to solve measurement problems). The results are shown in Figure 7.5 and Table 7.1.

The origin of entry can be observed to have been driven primarily by the exploitation of new technologies or materials. Towards the end of the period an increasing number of entrant firms were developing innovations that responded to techno-economic obstacles or exploiting scientific advances. Several firms involved in resolving technological imbalances were during the later half of the period entrant firms.

7.2.3 Summary

Overall, it appears that entrant ICT firms were particularly numerous during the recovery and boom period of 1984-1989 and the IT boom of 1995-1999. This supports the notion of waves of entrepreneurial activity in the early stages of new technologies (Schumpeter, 1939; Freeman et al., 1982; Utterback, 1994; Klepper, 1996). Moreover it has been found that young firms were particularly important in developing innovation during the second half of the period. The determinants of entry of innovating firms during these two periods can in part be understood by the technological opportunities that were presented following the diffusion of micro-electronics, the deregulation of the telecommunication markets in the 1980s and the wider diffusion of ICT technologies in the 1990s. The origin of entry was observed to have been driven primarily by the exploitation of new technologies or materials. Towards the end of the period an increasing number of entrant firms were responding to techno-economic obstacles or exploiting scientific advances. Several firms involved in resolving technological imbalances were during the later half of the period entrant firms.

While a wave of entry was observed in 1984-1989, entrant firms did not however contribute significantly to the surge in ICT innovations launched during and following the structural crisis. Rather, incumbent firms accounted for a majority of the innovations launched in the early surge. Moreover, these firms have continued to contribute a significant share of innovations during the latter half of the period (45.2% 1990-2007). Therefore, in the remainder of this chapter the focus will be directed towards examining the firm-level determinants of innovation in a selection of incumbent ICT firms.

7.3 Firm-level determinants of innovation

Having examined the role of entrant firms and some of the technological origins of entry, one may turn to the other side of innovating firms. How has the performance of firms affected innovation activity?

The following two hypotheses on firm-level determinants of innovation among incumbent firms can be distinguished:

H1: Innovation is catalyzed by unsatisfactory or falling profitability in the firm (Nelson & Winter, 1982; Cyert & March, 1963; Greve, 2003b; Antonelli & Scellato, 2011).

H2: Innovation is catalyzed by excess resources in the firm, so-called slack (Cyert & March, 1963; Penrose, 2009 [1959]; Pitelis, 2007; Antonelli & Scellato, 2011).

7.3.1 Model framework

The dependent variable in the model is the count of innovations launched in a certain year by a certain firm I_t. The general form of the model tested is

$$I_t = \phi\left(\sum_i(\beta_i X_{it}) + \sum_k(\gamma_k Z_{kt})\right) + \epsilon_t \tag{7.1}$$

where X is a set of measurements of the firms' performance, Z is a set of control variables, and where ϕ is a function allowing for non-linear specifications (as in the Poisson or negative binomial regressions). ϕ is for simplicity omitted in equations 7.4 and 7.5.

An issue in the behavioral theory of the firm is how aspiration levels are formed, and how firms adapt their aspirations to experience. In the theoretical framework developed by Cyert & March (1963), and further by Greve (2003a), firms are assumed to innovate when performance falls below the aspiration level of the firm. The formation of aspiration levels are assumed to be dependent on the historical outcomes of the firm in some target outcome. Unfortunately, it is typically difficult to obtain or create a direct estimate of aspiration levels. Instead authors have discussed different ways of estimating aspiration levels indirectly. Levinthal & March (1981) and (Greve, 2003a, p. 129), have suggested the following model for the formation of historical aspiration levels L_t:

$$L_t = \alpha L_{t-1} + (1-\alpha)P_{t-1} \tag{7.2}$$

where P is a measure of the performance (goal variable) of the firm (e.g. sales, rates of return to assets), and α is the adaptation coefficient which determines how fast aspiration levels adapt to the actual performance. This is possible to rewrite as the adaptive expectations model:

$$L_t = (1-\alpha)\sum_{s=1}^{\infty}\alpha^{s-1}P_{t-s}. \tag{7.3}$$

Greve (2003) suggests that the aspiration level coefficient α can be estimated by calculating the coefficient $\alpha \in [0,1]$, which in a full test of the performance feedback yields the highest log-likelihood. Historical aspiration levels can then be calculated according to equation 7.2. The model of innovation counts I takes the form:

$$I_t = \beta(P_t - L_t) + \sum_k (\gamma_k Z_{kt}) + \epsilon_t \tag{7.4}$$

where Z is a set of control variables. Greve (2003) also discusses the possibility of different relationships between innovation and performance feedback depending on whether the goal variable is above or below the aspiration level. This also motivates a test of

$$I_t = \beta_1(P_t - L_t)\delta_t + \beta_2(P_t - L_t)(1 - \delta_t) + \sum_k (\gamma_k Z_{kt}) + \epsilon_t \tag{7.5}$$

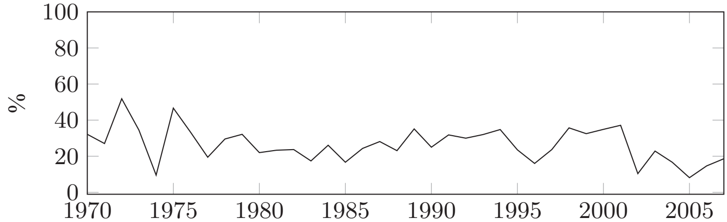
where δ_t is 1 if $P_t > L_t$ and 0 if $P_t \leq L_t$.

7.3.2 Sample and Economic Data

The examination of negative performance feedback has required the additional collection of economic data from the annual reports of firms in addition to variables available from the SWINNO database. This was done for 44 firms in the electric and electronic industries (SNI 30 to 33). Moreover, three larger corporate groups (AGA, Asea/ABB and Ericsson) were included in the sample.

This sample was created to investigate the connection between performance and innovation among companies engaging in innovation related to the micro-electronic revolution. To make a selection of ICT firms two general criteria were used: 1) the firms had launched at least two ICT innovations during the period 1970-2007 and 2) the firms were active during at least half (19) of those years without major breaks (for instance transformation of the firm to a holding company or similar non-production activities). The first criterion ensures that the sample captures persistent ICT innovators. The second criterion ensures that the sample captures firms that are able to compare their current performance with a record of previous performance. Short-lived firms are thus by design excluded from the sample. In general, selecting on survival may introduce logical errors. This is not considered an issue in the current case, since for short-lived firms, perfor-

Figure 7.6: Distribution of electronics innovations in the sample. Shares of total counts of electronics innovations (%).



mance feedback is on *a priori* grounds unlikely to have a significant impact on innovation unless firms may compare their performance with their previous performance. The empirical and theoretical interest is rather taken with whether there was such a mechanism among incumbent firms. Another reason to enforce this criterion is that panel data regressions require a large number of year-observations to give meaningful results on effects over time.

The first criterion singled out 150 firms. After examining available annual reports of these firms the second criterion was ultimately met by 41 firms. Other than these, three firms were included for special reasons. These were in fact active during more than 19 years but had breaks in the annual reports due to changes of ownership or restructuring.[2] In addition to these firms, AGA, ASEA/ABB and Ericsson were included to account for the dynamics of innovation activity in large corporate groups.

Thus the sample consists of 44 firms and 3 larger corporate groups. The 44 firms launched in total 181 innovations out of which 159 were electronic equipment innovations. The three corporate groups launched together 296 innovations of which 188 were electronic equipment innovations. The distribution of the count of electronic equipment innovations over time in the sample is compared with the overall distribution of electronic equipment innovations in Figure 7.6. The sample is evenly distributed over time, except for the last few years in which entrant firms launched a large number of innovations.

Data was collected systematically for sales, costs, current liabilities and

[2]Two firms, SRA and Sonab were active 14 years (1970-1983) but were later bought by Ericsson, continuing their activities as Ericsson Radio Systems. Malå Geoscience was active 16 years (1992-2007) but partially continued the activities of another firm, ABEM Geoscience.

Table 7.2: 44 electronic equipment firms and their respective counts of innovation.

Firm	Count	Firm	Count	Firm	Count	Firm	Count
Abelko	3	Gambro	5	Netzler & Dahlgren	8	Sieverts Kabelverk	6
ABEM Geoscience	10	Geotronics	2	Opsis	2	Sitek	3
AP Fix-turlaser	5	ICL Data	3	Optronics	3	Sonab	5
Axis Communi-cations	5	Ifm Elec-tronic AB	2	Origa Cylinder	2	Spectronic	6
C E Johans-son	7	Integrated Vision Products	4	Philips	8	SPM Instrument	3
Cerlic	2	Lorentzen & Wettre	5	Polaroid	4	SRA	3
Comator	2	Luxor	3	Radians In-nova	2	Standard Radio & Telefon	4
Conrad Ekengren	2	Malå Geo-science	2	Reflex Instrument	5	Swema	3
Denex	5	Micronic Laser System	6	Scan-ditronix	3	Tecator	9
Diffchamb	3	Mitec	4	Semtech	2	Telemetric	3
Doro	3	Multiq	3	Siemens	6	Utec	3

Table 7.3: Variables collected from the firms' financial accounts and the construct of independent variables.

Basic Variable	Description	
S	Total non-financial incomes	
C	Total non-financial costs	
DEP	Depreciation on capital assets	
L	Current liabilities	
A_c	Current assets	
INV	Merchandise inventory	
A	Total assets	
Dependent variable	**Description**	
$INNO$	Count of innovations by year of commercialization	
Independent variables	**Description**	**Calculated as**
Π_G	Ratio of gross profits to total assets	$(S - C)/A$
Π	Ratio of net profits to total assets	$(S - C - DEP)/A$
UN	Unabsorbed slack	$(A_c - INV)/L$
ΔS	Sales growth	$(S_t - S_{t-1})/S_{t-1}$
AGE	Age of firm	

current and capital assets, from the consolidated statements of income and balance sheets. The data that was systematically collected and the independent variables included in the regressions are described in the Table 7.3.

There are common issues with longitudinal firm financial data that need to be addressed. One issue is whether to use economic data for parent companies or for the corporate group (parent company *and* subsidiary companies). Parent company data avoids comparability issues stemming from the restructuring of corporate groups, or buying or selling of subsidiary companies, but is not typically representative for the economic performance of subsidiary companies. For the three big corporate groups, economic data for the whole corporate group, i.e. parent company and subsidiaries has been employed.[3] The sample of the 44 firms did not contain large corpo-

[3]A potential issue regarding these is the presence of unavoidable breaks in the financial reports of large corporate groups after major restructuring, divesting or acquisitions or ownership changes. If the unit of analysis is the corporate group, such restructuring may be viewed as producing very real changes in e.g. corporate profitability. In other series however, it may cause difficulties to produce consistent series. In this sample, inconsistency was only a major problem as regards Asea/ABB. While reasonable series of profitability

rate groups, but smaller firms that sometimes evolved into corporate groups. For these ICT firms the data for parent companies was preferred.[4]

Another issue is the irregular reporting of economic data. Several firms had broken accounting years (e.g. 1970-07-01 to 1971-06-30). As the resulting series are annual, a conversion method was used were each value for the calendar year (e.g. 1971) has been calculated as the weighted sum of the relevant broken accounting years. The weights are given by the number of overlapping months divided by the total number of months in the accounting years. For instance, given two broken accounting years, 1970-07-01 to 1971-06-30 (12 months) and 1971-07-01 to 1972-12-31 (18 months), the weights for the calculation of 1971 would be 6/12 and 6/18 respectively.

7.3.3 Regression models

A series of choices were necessary to arrive at the final model specifications. The first choice made was between a fixed effects and a random effects model to capture unobserved heterogeneity. In our case, the interest taken is primarily in the temporal and not the time-invariant effects. For this reason the fixed effects approach has been preferred in principle. Second, when the dependent variable is a count of events, a Poisson or negative binomial regression model are appropriate. The Poisson model is more robust in principle, why a Poisson fixed effects model is preferred. Test were used to test the adequacy of the Poisson and fixed effects specifications. In general, fixed effects model are however less efficient than random effects models. Hausman tests were used to assess the adequacy of this choice, which rejected the null of individual-specific effects being uncorrelated with regressors. Thus a fixed effects model may be considered feasible (Cameron & Trivedi, 2005). A common issue with the Poisson model is the equidispersion assumption, i.e. that the mean is equal to the variance. Poisson mod-

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and unabsorbed slack were possible to construct for Asea/ABB, sales growth however was not, due to acquisitions and corporate restructuring.

[4]There were two exceptions to this rule. Gambro evolved into a large corporate group during the period studied with many activities that have launched innovations. Another exception was Mitec Electronics that was divided in 1995 into a parent company and a subsidiary company, Mitec Instruments. The purpose of the parent company was to administer immaterial resources and it was not involved in production. Therefore the whole corporate group was chosen. The economic data was based on annual reports of the corporate group for 1995-1999 and - due to non-existent corporate annual reports for 2000-2006 - by adding together the figures of the parent company and the subsidiary company.

els will be biased if this assumption does not hold. The innovation count averages 0.2335 per observation and the variance is 0.6211. This may indicate a slight problem with over-dispersion (variance bigger than mean). Over-dispersion tests were therefore conducted on the models (Cameron & Trivedi, 2005). As the tests failed to indicate over-dispersion, the Poisson fixed effects model was preferred.

Another issue pertains to the possibility that returns on assets may be dependent on previous and current innovation activity through a positive effect on sales. The possibility was examined by running a test for reverse causality found in Table D.1 in Appendix D. It is also possible that returns on assets might be negatively affected by increased R&D costs, which would lead to spurious results. Due to inconsistency in accounting methods, R&D costs could not be systematically collected.[5] When presented, current R&D costs typically entered the accounts as depreciation of immaterial assets. Since however both profits before and after depreciation were collected it is possible to compare whether the results are similar before or after taking account of depreciation. This comparison is found in Table D.2 in Appendix D. None of these tests showed indications of reverse causality or risks of spurious results.

The tests of the impact of economic variables on innovation focus on the relationship between profitability, as measured by the rate of returns (net of depreciation) to total assets Π.

Control variables included were sales growth (ΔS), calculated as the annual rate of growth of sales and unabsorbed slack (UN) as the ratio of current assets (excluding inventories) to current liabilities.

7.3.4 Results

The quantitative analysis proceeds from a simple model that tests whether innovations were launched in periods of low rates of returns relative to aspirations $\Pi - L$, while controlling for the age of firms. All significant coefficients reported are robust to changes in aspiration levels, or omissions entirely of the estimation of aspiration levels. The estimation of aspiration levels for models 1 - 2B yielded an adjustment coefficient of 0.910, which in practice means a slow adjustment of aspirations to changes in performance.

Table 7.4 reports the results. The Models 1A and 1B reveal a negative

[5] Moreover, there are definition problems. Glete (1983) for instance warns about poor quality in R&D costs in Asea's financial accounts.

Table 7.4: Negative performance feedback in 44 ICT firms and 3 large corporate groups Results from a Poisson panel data model (fixed effects).

	Variable	Model (1A)	Model (1B)	Model (2A)	Model (2B)		Model (3)	
Baseline variables	Age	-0.039^{***}	-0.012	-0.039^{***}	-0.039^{***}		-0.052^{***}	
		[0.012]	[0.016]	[0.012]	[0.001]		[0.014]	
	Age^2	0.0002^{**}	-0.0003^{*}	0.0002^{**}	0.0002^{**}		0.0002^{***}	
		[0.000]	[0.000]	[0.000]	[0.010]		[0.000]	
Subcategory[a]					44 firms	3 corp. groups	44 firms	3 corp. groups
Firm-level variables	$\Pi - L$[b]	-1.145^{***}	-1.133^{**}		-1.23^{***}	-0.358	-0.962^{*}	-0.259^{*}
		[0.435]	[0.504]		[0.454]	[1.395]	[0.565]	[1.507]
	Lag 1						-0.242	0.368
							[0.538]	[1.672]
	Lag 2						-1.991^{***}	0.0084
							[0.631]	[1.616]
	$\Pi > L$			-0.755				
				[0.965]				
	$\Pi < L$			-1.329^{**}				
				[0.590]				
	ΔS		0.113					
			[0.515]					
	UN		-0.034					
			[0.0469]					
	Obs.	1303	1139	1303	1303		1186	
	Firms	47	46[c]	47	47		47	
	Log-Lik	-619.43	-424.29	-621.416	-621.34		-587.17	

Note: *, p<0.1; **, p<0.05; ***, p<0.01. Standard errors in brackets.

[a] In Models 2B and 3 the three corporate groups and the 44 other firms were allowed different intercepts for the variables included.

[b] Aspiration levels were calculated according to the method suggested by Greve (2003a). The equation $L_t = (1-\alpha)\sum_{s=1}(\alpha^{s-1}\Pi_{t-s})$ was estimated and the value of α chosen that maximized the log likelihood of $I_t = \beta_1(\Pi_t - L_t)\delta_t + \beta_2(\Pi_t - L_t)(1-\delta_t)$, where δ is 1 when $\Pi_t > L_t$, otherwise 0. α was estimated to 0.910 for models 1-2B. For Model 3, two lags were included in the estimation. α was estimated to 0.300.

[c] Reported sales for Asea/ABB were inconsistent due restructuring and have not been included.

relationship between rate of returns to assets relative to aspiration levels and innovation. Neither sales growth nor unabsorbed slack was found to have a significant impact in the models. Unabsorbed slack was tested for in various models, but was found to be insignificant. In Models 2A and 2B, the aspiration levels are estimated following Greve (2003a,b) and others, and the relationship between profitability and innovation is tested for periods when performance is above and below the estimated aspiration levels. Model 2B allows different effects for three corporate groups and the 44 companies. Both Model 2A and 2B reveal that there is a negative relationship between innovation launches and performance above and below the aspiration level. The coefficient is however only significant below the aspiration level. The assumption that firms react immediately to performance feedback is however naïve. In model 3, the lag structure is explored. Since the inclusion of lags implies a different view of how firms react to innovations, the best fitted aspiration levels were estimated anew specifically for this model by including two lags in the equation of formation of aspiration. This yielded an adjustment coefficient of 0.30, meaning that firms appear to adjust their aspiration levels faster than in the previous estimations.[6] Model 3 distinguishes between large and small firms. Among small firms there is a short term (0-2 years) negative effect of performance $\Pi - L$. The coefficient is significant for lag 0 and lag 2. The lags of two years is most significant, which tells us that innovation launches are more probable some two years after a drop in performance relative to aspirations. Unlike Model 2B, a significant relationship is found for the three large corporate groups for lag 0. However, this result was not robust to changes in lag structure.

These tests offer support for the failure induced innovation hypothesis as regards the current sample. The evidence of a negative impact of profitability is robust to changes in model types or specifications. However, there is no evidence of an impact of sales or unabsorbed slack. The results also show that innovations in the three corporate groups were not strongly responsive to the returns to assets. This may be interpreted as a support for the notion of institutionalized search, which is certainly plausible for large corporate groups. The result may however also be interpreted as a support for the view that response to transformation pressure and negative performance feedback is a relevant mechanism on the plant level rather than in large corporate groups.

[6]The results are robust to variations of the adjustment coefficient.

7.3.5 Response to Performance feedback

The results give statistical support for the hypothesis of creative response to firm-level negative performance feedback. The results indicated that among the firms studied the probability of innovation launches was higher during and following periods of negative performance feedback. There are however limitations to quantitative techniques and they may in this case only describe the average behavior. In this section, these results are subjected to further analysis by focusing on the history of some of the firms included in the sample and evidence on their innovation processes. *When and under what circumstances did negative performance feedback give rise to innovations?*

Moreover, it is of interest to understand, if firms have responded to negative performance feedback, how this was the case. Based on the analytical framework of March (1991), Greve (2007) has suggested that creative response to negative performance feedback is closely linked with exploration and product diversification rather than exploitation. Greve (2007) suggests and shows that explorative innovation is more strongly linked to negative performance feedback than are exploitative innovations. Therefore, as a focusing device, this section aims to describe firms' innovation responses in terms of the exploration of new product areas and technologies or the focus of activities to traditional areas.

Apart from the large corporate groups the small companies included have not to a great extent been the subjects of previous research. Axis Communications was the subject of a case study (Eneroth, 1997). Siemens AB, Philips AB, and Sieverts Kabel (Ericsson Cables) have published company histories for parts of the period studied (Lidén & Mattison, 1988; Siemens AB, 1998; Philips försäljning AB, 1983). Some firms, as Sonab, SRA and Spectronic have been described as parts of the emerging mobile telephone industry (McKelvey et al., 1997; Mölleryd, 1997). As a complement to existing literature on the firms, the information from annual reports and trade journal articles underlies the below descriptions. Annual reports contain not only financial accounts, but also more or less detailed accounts of the company history and can therefore provide self-reported accounts of the performance and, not seldom, the firms strategical response to the changes in performance. Together with the text material assembled in the SWINNO database it is possible to give an overview here of the innovation activity in these firms that may enrich the quantitative assessment of creative response. The selection of firms discussed below is based upon the availability of reliable sources. The overview is based on contrasting textual accounts of strategies with negative performance and positive performance with innovation activity or lack thereof.

7.3.5.1 Manufacturers of computers

Luxor, traditionally a producer of consumer electronics, was one of the firms that developed the highly successful ABC 80, Sweden's first personal computer. The development of ABC 80 was conducted in collaboration with DIAB (Dataindustrier AB) and Scandia Metric and launched in 1978. Meanwhile, Luxor's annual report in 1977-1978 described several strongly felt economic problems and challenges under the heading "The year past a year of crisis" (Luxor 1978). The TV and radio industry had, during the past years emerged as a "problem area" in the Nordic countries and Europe. In combination with an increased competition from Japanese and other Asian firms and a market saturation the industry found itself in a strongly negative situation. Luxor described its own development as negative but "surprisingly positive and stable" considering the situation. Luxor's negative development was described as mainly pertaining to: 1) the saturation of the TV markets, 2) lost market shares on the domestic market due to increased competition from international competitors and 3) Luxor's over-capacity, resulting from the installment of micro-electronic machines that facilitated production increases with extant personnel. In addition, an industry fire in October 1976 also contributed to the economic problems. Luxor's first response was to compensate its losses by increasing exports. This however came to contribute to requirements of market adaptation of its products and administrative problems. At this time Luxor coordinated its resources with DIAB and Scandia Metric to counter the saturation of traditional electronic equipment markets, an effort which led to ABC 80. This became the start of a new line of production. Luxor's other innovations were characterized by the exploitation of opportunities created by the development of ABC 80 and other opportunities brought about by the micro-electronics revolution. Around 1978 development was started of a micro-computer based system for carrier-frequency signalling, launched in 1982. In 1985, Luxor launched VARKON-3D, a software for CAD (Computer Aided Design). In 1984, Luxor was sold by its owner Investeringsbanken to Finnish Nokia that later closed down the computer division. From 1989, Luxor struggled anew with profitability problems. This time, rationalizations became the response to improve profitablity. An extensive action program was made involving the development of more competitive products, the rationalization of production and cost saving measures within the administration. This resulted in the shutdown of several divisions. Some were transferred to other firms in the Nokia corporate group. The parent company ceased production in 1991 (Luxor 1989; Luxor 1991).

7.3.5.2 Manufacturers of radio, TV and telecommunication equipment

Sonab and SRA were two manufacturers of home electronics that encountered severe negative transformation pressure during the 1970s. In 1978 SRA bought Sonab, and in 1983 both the parent company and subsidiary became part of the Ericsson corporate group under the division "Ericsson Radio Systems". These firms have been treated as separate (parent company and subsidiary) until 1983, after which they have been included in the sample as Ericsson.[7]

Sonab was a Swedish manufacturer of speakers started in 1966 by Stig Carlsson. The firm was struck by a negative transformation pressure already in the late 1960s. After having entered into an acute crisis, Sonab was bought by Statsföretag AB in 1969. The Swedish market was stagnating in Sonab's product areas and the return on total assets was negative in 1969-1970 and 1974-1976.

Sonab launched five significant innovations during the period of study. Three of these were paging systems that were focused on solving problems for companies in need of being able to reach mobile staff. In 1970 Sonab had built up a development department for industrial electronics specializing in the field of information transmission resulting in two new product segments: mobile radios and paging systems. The first product was marketed by the end of 1971 (Annual reports, Sonab 1970). Headhunter, launched in 1972 eliminated technical obstacles and exploited the new opportunity offered when Swedish Televerket made possible canals for responders.[8] In 1974 the markets were receding and the firm encountered administrative problems. Moreover, the investments in mobile radio and paging systems had become more time consuming and costly than was expected (Annual reports, Sonab

[7] Separate figures for the total assets of Ericsson Radio Systems have not been presented in the annual reports of the Ericsson corporate group.

[8] Most wireless paging systems used a loop to reach the mobile receivers. The disadvantage of a pure loop system was that mobile devices - anywhere, must be small - can not be sent back to the loop. The power requirement was too great, and there was also some other technical problems. Up until that point it was not possible to use wireless connections for voice transmission in Sweden, since there were no channels available for the paging system. But as Televerket had opened channels for responders in the 160 MHz band, new opportunities were provided (*Modern Elektronik* 1972:4, p. 24; *Elteknik* 1972:3, p. 26).

1975, 1976). In the fall of 1975 it became clear that the measures thus far undertaken were not enough and that more drastic measures were necessary. The Sonab group presented unsatisfactory results and was able to survive only thanks to support from the parent company. During 1976, an extensive reconstruction work was undertaken by simplifying the corporate group organization (Ibid). The audio and agency operations were divested and the operations were directed towards the advancing product segments: mobile radio and paging systems.[9] In the fall of 1976 a mobile telephone was launched, a success according to the company (Ibid). The phone was, like previous innovations, aimed to enable communication between mobile staff (*Verkstäderna* 1977:9, p. 68).

In sum, Sonab's response during the crisis was not an example of explorative search. Rather, the firm responded by launching new products in its traditional product areas.

The company Doro Telefoni was originally started in 1974 in Lund to compete with Televerket through the import of telephones to the Swedish markets. After going bankrupt, a new firm with the name Internovator Aktiebolag (later changed back to Doro) was started in 1982 to overtake parts of the previous operations.[10] Doro's development mirrors the deregulation of the Swedish telecommunication market. The main strategy was to exploit the markets as they were deregulated. In the annual report of 1998, the history of the firm is described in three phases. During the period 1985-1990 the monopolies were removed and the markets were successively opened. The growth strategy between 1991 and 1995 was to improve the product range and to launch products on the deregulated markets (Doro annual reports 1998). From 1996 the strategy was aimed towards strategic acquisitions for geographic expansion and internationalization.

While Doro launched a large number of products, the first significant innovation noted in the database was the mobile telephone "Doro Walk & Talk" (1997). From 1999, however, Doro encountered difficulties stemming from the saturation of the markets for home telephony and broadband. At first, a tough situation emerged due to the electronic component shortage resulting from the Asian financial crisis in 1997-1998. This created financial problems for Doro in 1999-2000, as the deliveries of electronic circuits were

[9] Moreover, all foreign subsidiaries, with the exception of the Finnish and Swiss, were sold or shut down. Remaining operations were divided into two independent subsidiaries of Statsföretag AB: Sonab Communications AB in Gävle and Lövånger Electronics AB in Lövånger.

[10] The annual reports pertain to this new company.

delayed or cancelled, in turn delaying Doro's own production. Furthermore high costs were becoming strongly felt. The response to the crisis were to increase the number of new product launches and to diversify towards other products than telephones, e.g. mobile telephone accessories. A significant innovation emerged among these development efforts: E-Range (launched 2005), a telephone, launched as the world's first module based telephone with a basic module and several additional ones (*Telekom idag* 2005:4, p. 39). Doro's profitability however did not recover during the period studied. Increasingly, Doro came to focus on one of its main divisions("Care Electronics", meaning telecommunication products for the niche market of elderly care.[11] This consolidation resulted in Handleplus 324 gsm, launched in 2007, a telephone aimed for elderly with disabilities.[12]

Like Doro, Spectronic was a firm exploiting market niches emerging from the deregulation of the telecommunication markets. It was started in 1972 by Per Siversson, shortly after the deregulation of the mobile telephone market. Naturally, the firm specialised in portable mobile telephones (Mölleryd, 1999, pp. 118-119). In 1985 development was started of what became the first portable telephone with all components in one circuit. According to the CEO Per Siversson, it was the world's smallest portable telephone at the time (*Ny Teknik* 1989:40, p. 38; 1990:42 p. 6, 1990:51-52, p. 14). In 1992 a portable telephone with built-in pocket terminal for the NMT system was launched (*Ny Teknik* 1992:12, p. 5; 1993:10, p. 18).

The performance of Spectronic reached a historic high in 1992. After 1992 Spectronic however encountered decreasing returns, and negative results from 1997. In 1997 firm initiated intense development efforts to develop a new product base (Spectronic 1997, annual report). In 1999 Spectronic launched a multi media telephone with a built-in camera. It was also in 1996-1997 that the firm started developing "Sidetouch", a button-less mobile telephone, launched in 2002 (*Ny Teknik* 2002:15, Part 2, pp. 10-11). This was an entirely new innovation to the firm.

7.3.5.3 Manufacturers of printers, cameras and video products

Axis Communications started in late 1984 to develop and sell printer interfaces. In 1984, Martin Gren and Mikael Karlsson had experimented with a print converter for IBM systems, eliminating obstacles to the connection of different brands of printers and computers. Print interfaces and print con-

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[11] The other two were the traditional "Home Electonics", and "Business Electronics".

[12] Starting in 2007 Doro focused only on Care Electronics, which turned out to turn the negative numbers around.

verters also made it possible to share printers within a building. This niche market, neglected by IBM, would turn out to be a mass-market (*Ny Teknik* 1994:44, p. 32). At that time the product life length was however estimated to be short and Axis saw a receding market for its IBM printer interface. Axis decided in 1987 - a troublesome year - to put its efforts into developing a laser printer to secure its future. However, due to technical problems and a misjudgment of the market, development had to be cancelled in 1990. After this failure, Axis focused its efforts towards expanding into the area of print servers. A significant innovation was developed and launched in 1991 (Eneroth, 1997, pp. 81-86, 178-181; *Ny Teknik* 1994:44, p. 32). Axis' third development phase started in 1995/96, when Axis took the step to become a producer of network products (as opposed to printer communication products). It was the first company in the world to develop and launch a centralized IP camera, 'Neteye', becoming a highly successful product on the world market, re-transforming Axis into a worldwide leader in the field. During 1998-2001 Axis Communications faced negative results, resulting from the market saturation of the firm's more mature products (document and storage servers). The response of the Axis corporate group was structural reorganizations aimed to restore profitability and improve the sales development, primarily by focusing the business activity on the network products. The deteriorated investment climate on the IT market also made personnel reductions necessary. The crisis was overcome as the market development of network based cameras and video products was positive, due to the shift to digitalized cameras. In 2004 Axis had taken steps in this direction by the launches of new generations of network cameras and video servers. Only in 2004 Axis had launched 20 new video products (Annual reports for the Axis corporate group 2000-2004).

In sum, Axis was a growth firm characterized by a strong positive transformation pressure. It is clear that innovation activity in this firm was certainly affected by strategic and organizational challenges. However, the case of Axis does not offer a clear-cut story of creative response to negative performance feedback. The crisis of the 1990s did not affect the profitability of the firm and the negative performance feedback during the IT crisis spurred no significant innovations. Rather the response appeared more adaptive in character: strategic change and organizational restructuring towards the firms' growing product segments. An innovation in these product segments was developed in collaboration with Telia Research (2000).

Integrated Vision Products (IVP) was founded in 1985 to exploit an image sensor for cameras and vision systems (called LAPP 1100) developed by Robert Forchheimer and research engineer Anders Ödmark. During its first years the activities were financed by STU. The circuit was launched in 1988 (*Elteknik* 1988:11, p. 7). IVP was practically alone on the world market with a circuit of this type. Based on this technology two other innovations were launched in the next few years: a camera built upon the circuit and an image processor with a built-in signal processor (*Elteknik* 1991:14, p. 7; *Automation* 1991:6, p. 21). IVP was practically a start-up firm, exploiting the image sensor LAPP 1100 for its innovations. Apparently no innovations were developed as creative response.

7.3.5.4 Optical measuring equipment

Radians Innova was founded in 1979 by Bengt Kleman, (Försvarets Forskningsanstalt) and Chalmers Tekniska Högskola to commercialize a technology for laser based micro-processing (*Ny Teknik* 1984:16, p. 38). Radians was profitable until 1994. In 1995 Radians Innova decided to redirect its activities towards the promising Telecom market. The activity was increasingly focused on the development of tunable lasers for fiber optic testing and measuring equipment. In the fall of 1998, the firm started to develop the tunable laser "PICO-E", launched in 2002. Due to profitability problems following from the Telecom bust, Radians was sold to the American firm Thorlabs in January 2004. This fate was shared with fellow producer of tunable lasers Altitune (see page 208). While the tunable laser innovation was developed and launched in a period with negative performance feedback, the sources to not provide evidence that Radians Innova's tunable laser innovation was in fact an example of failure induced innovation.

Micronic started as a research project led by Gerhard Westerberg on micro litography at the Royal Institute of Technology during the 1970s. Micronic developed a new method, Laserscan, for the production of masks for integrated circuits. The manufacture of masks for integrated circuits with the then available technology (photographic lithography) tended to become a production bottleneck due to the complexity of mask patterns (*Elteknik* 1976:7, pp. 22-28). The firm went bankrupt in 1987, but was reconstructed in 1989 as Retiscan, later Micronic Laser Systems. The firm's core technology was the laser based lithography equipment. In 1993-1995 a weak semiconductor industry however forced Micronic to seek other markets for its technology, mostly the computer and TV screen manufacturers in South East Asia. The firm was therefore severely affected by the Asian crisis in 1997-1998 (MLS annual report 2006; *Ny Teknik* 2000:4, p. 11). While facing negative profitability, technological progress allowed the firm to reenter the semiconductor market in 1999. This led to the launch of Omega 6000 in 2000 (*Verkstäderna* 2000:4 pp. 6-7; *Ny Teknik* 2000:4, p. 11). A new laser based technology (called Spatial Light Modulator) for photo mask production was also launched in 2001 (*Elektroniktidningen* 2001:5, p. 12; *Ny Teknik* 2004:51-52, p. 8) adding to the firm's product porfolio. Micronic successfully adapted and could turn the negative numbers to positive towards the end of the period studied.

7.3.5.5 Manufacturers of other measurement and control systems

C E Johansson AB (henceforth CEJ AB) was started in 1911 by one of the more famous Swedish inventors, engineer Carl Edvard Johansson. In 1969 CEJ launched it's first coordinate measuring machine, which became a growing product segment of the firm. During the period studied CEJ AB commercialized 6 innovations contained in the SWINNO database, 3 of which were innovations developed to solve technical measurement problems. Towards the end of the 1970s the firm's export goods faced diminishing demand and the return on assets were unsatisfactory which led to a restructuring of the activities of the firm (CEJ annual reports 1976). In 1977 development began of what came to be "Jocal". It was the world's first electronic calliper, launched in 1980, solving the technical problem of allowing measuring fixtures to measure several details. The sales of the firm in the domestic and export markets improved in 1978-1981 but rates of return were unsatisfactory and negative in 1980-1983. In 1983 a rationalization program was carried out, by cost rationalizations and eliminating unprofitable products and activities. As a result 120 employees were laid off from February 1984. However, it was not until after the crisis of the 1990s that CEJ broke its record of low profitability, aided by sales from a new product "Saphir" (launched in 1993) and the Swedish export industry (CEJ annual report 1993).[13]

Though no immediate evidence of creative response can be found, the innovation activity of the firm was concentrated to the period when the firm was under pressure to transform.

Mitec Electronics/Mitec Instrument launched 4 innovations during the period studied. Two of these innovations were "start-up" innovations. These were launched in 1983, one year after the firm start. These were portable measuring equipments for temperature registration and for technical measurements on electric motors. The other two were launched after a period

[13] This new product has not been captured in the SWINNO database but was mentioned in the annual reports as an innovation of importance to the firm.

of financial distress for the firm. The new market situation stemming from the IT bust led to a transformation of the Mitec corporate group. New products were developed for new customer categories and markets. In 2001 and 2006 Mitec launched products based on wireless measurement via the GSM network and Internet based measurement services. This product area was a diversification to the firm, resulting from a transformation of the firm's activities.

7.3.5.6 Cable products

Sieverts Kabelverk was started by Max Sievert as an industry for the production of conduit wire. Since 1928 it was owned by L M Ericsson. The firm saw a thorough restructuring during the period of study due to the shrinking market in the 1970s and Sieverts Kabelverk's over-capacity. A business concentration was carried out and in 1985 Sieverts Kabelverk changed its name to Ericsson Cables (Lidén & Mattison, 1988; *Kontakten* 1988:1, p. 3). During the 1990s the firm carried out more continuous restructuring, rather than responding to (sudden) negative performance feedback. The conditions for the production of power cables were changing and the operative activity was successively redirected towards the growing field of optic fibres for the needs of the telecommunications and computer industries as well as future networks for cable-TV. This redirection of the activity of the firm resulted in several 'non-traditional' significant innovations during the 1990s: a fiber welding equipment aimed to reduce losses (*Elteknik* 1991:3, p. 29) and a new-to-the-world optic fiber welding equipment (*Elektroniktidningen* 1995:7, p. 4). Ericsson Cables also launched a cable installation tool (called Ribbonet) in 1999 to enable IT services for home users (by supplying the required bandwidth).

7.3.5.7 Medical equipment

Siemens has a long history in Sweden. The first Siemens products were launched in Sweden already in the 1850s. Siemens AB was established in 1893. During the postwar period, Swedish Siemens was responsible for cutting edge innovations in the medical field. The first pacemaker was developed in 1958 by Siemens-Elema, followed by several innovations in the growing medical field. Swedish Siemens was also one of the companies that were part of Siemens' initiative in the burgeoning computer market. Despite a successful innovation record, Siemens was hit hard by the recessions during the 1970s: first the investment downturn in 1971 and then by the increased labor costs and shrinking export markets in 1976-1979 (Annual reports Siemens 1971, 1976 and 1978). Siemens responded by extensive rationalisations. The number of employees diminished with 200, of which half were transferred to Siemens computer division, Unidata (Annual report 1976; Siemens AB, 1998, pp. 21-23, 31-32). Unidata was however liquidated in 1976. While Siemens was hit hard by the crisis, the innovations launched by Siemens were primarily in the expanding market area of medical equipment. In 1972 Siemens-Elema started development of new carbon laimnate based X-ray tables to solve technical problems with the previously used phenolic resin panels, enabling decreased X-ray dosage.[14] In 1980, Siemens Elema launched a mobile micro-computer based X-ray equipment that likewise was aimed to decrease the necessary X-ray dosage (*Modern Elektronik* 1980:11 pp. 11, 36).

7.3.5.8 Other firms

Origa Cylindrar was a firm started in 1966 under the name Mecmatic. Disadvantages in the conventional technology led to the development in 1968 of a rodless cylinder aimed to eliminate techno-economic problems arising from the length of rods in conventional pneumatic cylinders (*Verkstäderna* 1972:11, pp. 565-6; *Sågverken* 1972:11, pp. 793, 795; *Transport Teknik Scandinavia* 1986:12, pp. 28-29).[15] The 1980s was characterized by high sales but decreased profitability for Origa Cylindrar, in particular the years 1984-1985. It appears that the firm responded to a negative performance feedback by product diversification. In 1986 the firm launched a microprocessor based control system for robots, which must be considered a diversification from its earlier focus on cylinders (*Skandinavisk Transport Teknik* 1986:12, pp. 28-29). The innovation was described as entirely new to the firm.

[14] "Up until 1972 the production of X-ray tables used phenolic resin panels in the table. The problem with these discs was that they absorbed quite large amounts of X-rays , which meant that you had to increase the dose X-rays. This was something you wanted to avoid, high doses of X-rays is not good for the patient or the personnel working with the equipment. [---] Within Siemens-Elema they decided to do something about the problem" Translated from (*Plastforum Scandinavia* 1981:4, pp. 90-93).

[15] The conventional rodless pneumatic cylinder with a piston rod could often become troublesome at longer transfers. Another problem that could occur was the risk of buckling of the piston rod. To cope with the problem it was often necessary to choose a larger and more powerful cylinder, leading to a more expensive design and even greater space requirements (*Verkstäderna* 1972:11, pp. 565-6).

7.3.5.9 The Large Corporate Groups

The three corporate groups Asea/ABB, Ericsson and AGA developed together a large number of ICT innovations during the period studied. A result obtained in section 7.3.4 is that pattern of innovations in these corporate groups cannot be explained by negative performance feedback. Certainly, it is very plausible that these corporate groups rather had a continuous research activity in many product fields at any one time (Glete, 1983; Almqvist, 1992; Pettersson, 2002; Westberg, 2002). This does not however imply that innovation was not influenced by transformation pressure. Rather, negative transformation pressure may have influenced strategic reorientations in terms of divesting unprofitable operations and reorientations towards growing markets. This section does not aim to give a full treatment of the history of these three firms, but rather indicate some of these reorientations, focusing on AGA and Asea/ABB.

Several technology shifts have taken place in these three firms. The innovations developed by the three corporate group is summarized in table 7.6. Ericsson emerges as an overall very consistent innovator in hardware ICT products, mostly telecommunications. Ericsson's move towards mobile telephony has been briefly described in section 4.4.3.1 as stemming from the development of AXE and NMT, after realizing the failure of its efforts in the area of business information systems. However, Ericsson's technology shifts have in a sense not been quite as dramatic as those of AGA and Asea/ABB.

Asea and AGA were both firms that developed a large range of products, invested continuously in R&D and came to respond to the transformation pressure by strategic reorientation in the 1970s, albeit in entirely different ways.

Asea/ABB launched 177 innovations during the period studied. Asea was started in 1883 as Allmänna Svenska Elektriska AB, and was at the outset supplying electrical power equipment for the burgeoning electric lighting industry. By strategic acquisitions and expansion the corporate group had by the early 1960s a broad set of industrial operations in the electric power and electronic equipment fields. Apart from Asea's conventional products, subsidiaries or divisions produced turbines, cables, nuclear reactors, locomotives and electronic equipment (Glete, 1983, pp. 276-295).

Asea was one of the most instrumental players in the early microelectronics revolution in Sweden. In Table 7.6 this can be seen its launching of 56 hardware electronics innovations during the period 1970-1989 to which come several industrial robots developed. Asea's operations in electronics

Table 7.6: Innovations in AGA, ASEA/ABB and Ericsson by product groups, 1970-2007.

	AGA	ASEA/ABB[a]	Ericsson
1970-1989			
Hardware ICT products 1970-1989	10 (55.56%)	56 (52.34%)	32 (96.97%)
Software products	0 (0%)	2 (1.87%)	0 (0%)
Machinery and transport equipment	5 (27.78%)	33 (30.84%)	1 (3.03%)
Other	3 (16.67%)	16 (14.95%)	0 (0%)
1990-2007			
Hardware ICT products 1990-2007	0 (0%)	33 (47.14%)	58 (89.23%)
Software products	0 (0%)	8 (11.43%)	2 (3.08%)
Machinery and transport equipment	2 (40%)	25 (35.71%)	2 (3.08%)
Other	3 (60%)	4 (5.71%)	3 (4.62%)
Total count 1970-1989	18	107	33
Total count 1990-2007	5	70	65

Note: Hardware ICT products correspond to SNI 30-33, Software products to SNI 72 and Machinery and transport equipment to SNI 29 and SNI 34-35.

[a] For ASEA/ABB, industrial robots make up most of the innovations in machinery and transport equipment (SNI 29 and 34-35).

grew from its production of rectifiers in Ludvika and its design laboratory in Västerås. Interest was taken in the properties of semiconductors as rectifiers and in electronic apparatuses to solve technical problems in the design laboratory. In 1954 Asea together with L M Ericsson established the Institute for Semiconductor Research (Institutet för Halvledarforskning), which became Asea-Hafo AB in 1969 (Glete, 1983, pp. 319-33). Towards the end of the 1960s Asea moved into robotics and became the first firm in the world to make commercially available a wholly electronic micro-computer controlled industry robot in 1976 (called "IRB 6"). Asea was however not unaffected by the structural crisis and profitability became unsatisfactory towards the end of the 1970s. Led by CEO Percy Barnevik, the response became to implement a programme to focus Asea's operations towards advancing products, for instance industrial robots, power transmission and electronics, and to diminish or divest operations in unprofitable traditional segments (Glete, 1983, pp. 354-355). In 1988 Asea merged with the Swiss company Brown, Boveri & Cie to form ABB.

From its start, the strategy of ABB was largely aimed at globalization (or "being local worldwide", see Bélanger, 1999) and strategic acquisitions. A main innovation during the second half of the period was Powerformer (see section 6.4.2.1). This was viewed as one of the greatest breakthroughs in the firm's history. However, towards the end of the 1990s, ABB made the strategic decision to divest its operations in heavy electronics, such as AdTranz and Power Generation and focus on products more closely related to ICT, notably software programs for automation (Fridlund, 2007). Among the innovations that emerged in this reorientation was "Industrial IT", an automation software that enabled the connection of production with transaction systems, developed from the recognition of problems in Computer Aided Plant Engineering in the late 1980s (*Kemivärlden* 2000:12, p. 29; *Verkstäderna* 2001:1, pp. 38-39; 2003:7, pp. 24-30). ABB was heavily struck during the crisis of 2000-2001 and decided to halt the set of products developed around Powerformer.

AGA's research and development activities were characterized by constant experimentation (Westberg, 2002), the development of a broad range of products and a series of technology shifts (Almqvist, 1992; Westberg, 2002). In a study of AGA, Westberg (2002) has argued that AGA's technology shifts took place by way of continuous adaptations to market demand.[16] Started in 1904 as a producer of acetylene gas, AGA was towards the mid 20th century a firm with an impressive range of products encompassing ra-

[16] The AGA cooker was, according to Westberg (2002) the one exception.

dio and TV equipment, welding machines, batteries, mobile radio, the commercially successful AGA cooker (launched in 1929), respiratory equipment, freezers, AGA's Geodimeter (geodetic distance meter) and infrared camera technology. AGA even produced cars (Westberg, 2002). During the post-war era AGA moved its operations from its traditional gas operations to high technology and electrical products, such as radio and television (Westberg, 2002). AGA's entry into high electronics took place when, in the 1960s, AGA's radio and TV segments faced tough international competition. Thermovision was an infrared camera technology launched in 1965. AGA Innovation started in 1968, developing batteries, welding equipment and solar heating equipment (with AGA Heating).

AGA developed 23 innovations during the period studied out of which 10 were hardware ICT products, all launched in the period 1970-1989 (see Table 7.6). Many of the innovations in hardware electronics were based on the Thermovision camera system or AGA's geodimeter. However, the effort into electronics was ultimately deemed unsuccessful. In 1978 AGA acquired Frigoscandia, a world leading firm in freezing technology and focused its activities back to the traditional gas operations (Almqvist, 1992). The other activities were divested and sold. Hence, AGA launched no ICT innovations in the 1990s or 2000s. Today, AGA is primarily a gas supplier, owned since 2000 by The Linde Group.

In sum, Asea / ABB and AGA are examples of large corporate groups with strong traditions of experimentation and institutionalized search, through project activities and broad product programmes. They are also examples of two completely different paths taken. AGA took a path towards advancing product groups, but later chose to consolidate its activities. Asea / ABB took a path towards globalization and continued adaptation towards expanding product groups.

7.3.6 Summary: reorientation as creative response

The previous analysis suggests that most clear-cut qualitative examples of creative response to negative performance feedback can be understood as *strategic reorientations* or creative response by entering into new product areas. Comparing the evidence of negative performance feedback across firms it is recognized that the most cases of creative response were firms that were under pressure to transform but able to reorient their activity through innovation. An especially clear case was Luxor's personal computer ABC

80, which resulted from a reorientation from the saturated home electronics markets to the burgeoning field of computers. Only in a few cases were there examples of firms responding to crisis by exploiting the firm's traditional product technology, or by consolidating to traditional market segments. Sonab stuck to developing mobile radio innovations during the 1970s. AGA responded to a negative performance feedback during the 1960s by focusing on high technology electronics, but later came to consolidate to its gas operations. Doro both diversified (by moving into mobile telephone accessories) and consolidated (by focusing on care electronics).

7.4 Conclusions

This chapter has investigated the role of entrant and incumbent firms in the hardware ICT industry. It has, as it were, investigated the micro-basis of the ICT technology shift.

Innovations in the ICT technology shift were driven by both positive and negative factors at the firm-level. A role in the ICT technology shift was played both by entrant firms and incumbents. While incumbent firms were more important in the 1970s, it was shown that new firms had become more important in ICT innovation during the latter half of the period. It was shown that market entry of firms innovating in the electronics industries took place in particular during the periods of economic expansion 1984-1989 and 1994-1999. The first wave of entry was largely driven by opportunities from microelectronics. The second wave was largely driven by technological opportunities and the observation of technological imbalances in the telecommunication industry.

In the main part of the chapter firm-level determinants of innovation among 44 ICT firms and three larger corporate groups (Asea/ABB, Ericsson and AGA) were discussed. No statistical support could be offered for the hypothesis of a role played by excess resources or sales. The results however offered support to a hypothesis of negative performance feedback also in the advancing ICT sector. The way in which firms have responded to negative performance feedback was analysed in a last section of the chapter. Many firms responded to negative performance feedback by diversifying to new product areas or into growing market segments (e.g. Luxor, Doro Telefoni, Siemens). Comparing the evidence of negative performance feedback across firms it is recognized that the most clear-cut cases of creative response were firms that were operating in receding markets but able to reorient their activity towards advancing markets through innovation. This strategy appears, from the limited sample studied, to have been common. However, differences in innovation strategies and responses to crisis were present among firms. Some firms innovated in periods of crisis but did not diversify (e.g. Sonab) but rather continued to rely on their product technology.

No evidence could be given for a statistical tendency of large corporate groups to develop innovations due to negative performance feedback. These corporate groups have instead followed a pattern of "institutionalized search", having a large range of products in their pipelines. However, the company history of the three could be argued to support an idea of strategic reorientation towards growing product fields as the result of insatisfactory economic performance.

In sum, it appears that the ICT technology shift finds its basis in all of these types of driving forces: large incumbents that have emerged early at the technology frontier by way of institutionalized search, small incumbents that are induced to innovate in new product fields by falling profitability, and waves of entrant firms that have responded to opportunities and the recognition of technological imbalances.

8. Conclusions

This thesis examines to what extent and how innovations in the Swedish manufacturing industry have been influenced by economic and other factors during the period 1970-2007. A recent line of literature (Antonelli & Scellato, 2011; Antonelli, 2011b,a) has revived Schumpeter's notion of innovation as *creative response*. Innovation is understood as one of the main possible measures taken "outside of the range of existing practice" (Schumpeter, 1947, p. 150) in response to changes in the conditions of firms, industries or economies. This thesis has made use of this notion to analyze the driving forces of innovation and, by extension, the driving forces of industrial transformation. Previously, varying accounts of the driving forces of technological change have been given. A systematic and holistic empirical picture of the driving forces of innovation at the firm, industry and aggregate level has however been lacking. Making use of a new database on Swedish innovations this thesis has aimed to overcome this research gap.

Employing both quantitative and qualitative data from the SWINNO database, the study has answered questions of *to what extent* and *how* different factors have contributed to the development of innovations over time (chapter 4), across industries (chapter 5), in development blocks (chapter 6) and on the firm-level (chapter 7). The study has shown that numerous problems, obstacles and opportunities have spurred innovation activity and that such impulses to innovation have differed across sectors and followed marked patterns over time.

In what follows below I will not only summarize previous results but also provide a synthetic overall view of the driving forces to innovation at the firm, industry and aggregate level.

8.1 Summary of main results

The results can first of all be summarized in the observation of two qualitatively different patterns of creative response through innovation over time and across industries that account for the bulk of innovation activity during the period of study. This study has understood negative factors as economic, environmental and organizational problems and positive factors as technological opportunities and technological bottlenecks. The first pattern was driven by a negative transformation pressure connected with environmental, social and economic problems that emerged in the traditional oil-dependent industries and Fordist industries closely connected to mass production and consumer durables. Innovations responding to *negative* transformation pressure peaked during and following the structural crisis of the 1970s, but increased somewhat towards the end of the period studied. The second pattern of innovation was driven by technological opportunities but also by overcoming problems and obstacles connected with the new development blocks surrounding ICT and biotechnologies. Two surges of innovation driven by such *positive* transformation pressure took place during and following the structural crisis of the 1970s, and the end of the 1990s. Out of 4140 innovations, innovations citing positive transformation pressure were 1984, and negative transformation pressure 1067. Together these patterns have made up the bulk of the innovations developed and commercialized during the period studied.[1]

Chapters 5-7 examined the specific positive and negative determinants of innovation on the industry-level, in development blocks and on the firm-level in the ICT industries. The main results of these chapters may be briefly recaptured:

- Chapter 5 arrives at the general suggestion that industries with increasing relative volumes and counts of innovation have been driven by technological opportunities. Industries characterized by stagnating or decreasing relative volumes have typically had decreasing counts of innovation and problem-solving activity has been directed towards rationalizing production or solving problems involving negative externalities from production activities. Industry response has however been determined by historical factors. Some industries have

[1] The remainder were innovations that resulted from institutionalized search, or merely aimed at the improvement of the performance of previous products. These innovations decreased secularly during the period and cannot account for the surges observed.

failed to compete or exploit opportunities (inhibited advancers) or have failed to solve problems (stagnating and receding). Innovation activity within industries has thus followed particular patterns of creative response determined by positive and negative transformation pressure, but also historical circumstances.

- Chapter 6 reveals how innovation activity has co-evolved in ten plausible development blocks. The statistical and qualitative analysis reveals that several of the communities found were focused on resolving technological imbalances, either under a fundamentally negative transformation pressure, as in the forestry industry during and following the structural crisis of the 1970s, or a positive transformation pressure, as in the telecommunications industries during the 1990s. In these cases the innovations involved were parts of smaller or broader development blocks centered on the exploitation of new technologies or the overcoming of technological imbalances.

- Chapter 7 examines the micro-basis of the ICT technology shift. Firm-level driving forces of innovation were examined in the hardware ICT industry. Large incumbent firms were particularly important during the early technology shift in the 1970s. Many large corporate groups were carrying out institutionalized search for new products and had entered electronics early on. Small incumbent firms on the other hand were often found to search for new opportunities when facing lower profitability. Negative performance feedback was found to have spurred the entry into electronics or strategic reorientations towards new product groups. New entrant firms were to a large extent contributing to the surges of innovation activity from the 1980s and onwards. Two waves of entry of innovating firms took place, in 1984-1989 and 1994-1999. The innovations launched by these entrant firms were driven by the new technological opportunities and the observation of technological imbalances in the telecommunication industry.

8.1.1 Negative transformation pressure

One pattern of innovation was intimately connected with the economic, environmental and social problems of the oil-based, automobile and consumer durable development blocks that surfaced in the 1970s and 1980s. To a great extent it has reflected economic, social and environmental problems that surfaced during the structural crisis in the Fordist and oil- and fossil fuel based production system.

These innovations explain a significant part of the surge in innovation activity during and following the structural crisis. By contrast, during the 1990s negative transformation pressure did not to a large extent contribute to the surge in innovation activity.

Chapter 6 shows that several of these problem complexes formed the core of sets of interdependent innovations across industries. Plausible development blocks were found centered on construction, wood and basic metals, the pulp and paper industry, the forestry sector, and, responding to environmental problems, in the automotive industry and renewable energy technologies. During the 1970s several industries came under a strong negative transformation pressure, which induced firms to develop innovations to solve techno-economic problems hindering the rational or profitable production of goods. A case discussed in Chapter 4 is the forestry industry in which several innovations were developed as creative response to negative transformation pressure, originating in a set of closely interrelated social, technical and economic problems. In other industries firms responded to adversity by a strategic reorientation towards new products during the 1970s and early 1980s. This was the case in the shipbuilding industry, where firms reorientated towards the offshore market.

Other than the economic crisis of the traditional industries (metals and shipbuilding in particular), there were growing labor market conflicts that followed from the dissatisfaction with the work environment in Fordist production. Moreover, increased political attention was paid to the growing problem of environmental pollution of the oil-dependent and other industries. There were thus three principal aspects of negative transformation pressure that spurred creative response: economic, organizational and environmental problems.

Another set of problems that surfaced during 1970s were related to the working environment in the old industries. This was the case in the forestry, mining and engineering industries in particular. These problems concerned occupational safety, the use of toxic substances (such as organic solvents, asbestos and welding gas) or the in-house factory or firm working environment. In both the forestry and mining industries labor strikes and organizational conflicts may have contributed to increased efforts to deal with these problems. The mining industry struggled with dusting and occupational injuries. The engineering and construction industries had problems with occupational noise and injuries from vibrations in drilling operations. Other work environment problems were related to toxic welding gases and the use of organic solvents and harmful materials such as asbestos.

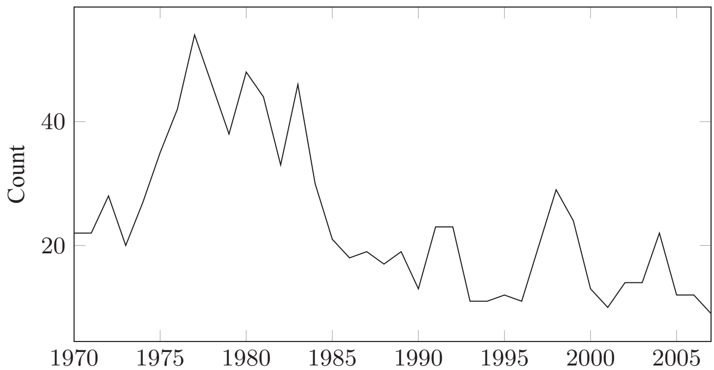
The creative response to environmental problems can in part be explained by environmental legislation, energy policy and an increased awareness of the issues that began in the 1960s. The energy and oil crisis of the 1970s intensified the search for new energy saving production processes and products, as well as alternative fuels and attempts to reduce oil dependency. These were predominantly innovations within the framework of the old development blocks, exemplified by the introduction of two-way catalysts and emission control technologies. The energy crisis had in particular an observable impact on innovations relating to energy distribution, such as ventilation apparatus, heating radiators, heating pumps, or ship and automotive engines. Other innovations were more "radical" in character, aimed to replace key factors in the oil, automotive and consumer durable development blocks. Such were the attempts to develop electric vehicles and many of the renewable energy technologies employing biomass, solar energy and wind power aimed to replace fossil fuels and oil based production. These development blocks have typically faced techno-economic obstacles to the introduction. For instance, the limited life length of batteries for electric cars spurred several problem-solving innovations. Towards the end of the period innovations in renewable energy technologies begun to resurface. These spawned by a renewed debate and the maturity of markets, e.g. for solar power in Japan. These areas had still techno-economic obstacles to be overcome. Arguably, "carbon lock-in" (Unruh, 2000) may yet pose economic as well as institutional obstacles to the wider use of renewable energy technologies.

In sum, the pattern of negative transformation pressure reflects the deeper character of the structural crisis. The crisis was not only an economic crisis, but also an energy, cost, and in some respects a social and institutional crisis.

8.1.2 Driving forces in the third technological revolution

A second pattern of innovation was intimately connected with new development blocks surrounding micro-electronics, information and communication technologies and biotechnologies. These technologies have evolved in a pattern of two surges. The basic results of chapter 4 suggest a surge in

Figure 8.1: Innovations driven by negative factors.



innovation activity during and following the structural crisis of the 1970s and a surge during the IT boom of the 1990s. These surges have signified a broader technology shift carried by the exploitation of microelectronics and biotechnologies in particular. In chapter 4 and 6 it was shown that these surges were different in character. ICT innovations during the 1970s and the 1980s formed a development block centered on industry automation, through the development of control systems, computer controlled machinery, automation equipment and automatic guided vehicles. Innovations during the 1990s were forming a development block centered on a wider exploitation of microelectronics and the resolution of imbalances in the Internet and telecommunication infrastructure. This expansion also spurred innovations in consumer electronics and a wider diffusion of ICT. Thus, to some extent the focus of transformation shifted from general industry to final consumption.

8.1.2.1 Long swings and technology shifts

The new technologies have evolved by way of overcoming technological, economic and institutional imbalances in a pattern of long swings of roughly 20 years of duration (compare Schön, 1998), in which transformation has culminated in the mid-1980s and the beginning of the 2000s. As shown in chapter 7, both incumbent firms and new entrant firms have been important in this process.

In the post-war decades innovation activity solved technical bottlenecks in the development of electronics. The integrated circuit was the response to the increasing complexity of transistor-based systems, what has been called the "tyranny of numbers." A key event was the development of the microprocessor, launched by Intel in 1971. Now, the information processing capacity of a digital computer was contained on a single chip and could be mass produced at a low cost. This was the event that finally enabled the wider diffusion of computers and electronics (Bresnahan & Trajtenberg, 1995; Langlois, 2002).

From the beginning of the structural crisis the vast opportunities created by the microelectronics spurred a large number of Swedish innovations in machinery, computers and electronic equipment.

Between 1973 and 1983, the microelectronic opportunities coupled with the economic slow-down led to explorative search for new products. Early on, large incumbent firms both had the capacity and were spurred to develop innovations in the new areas of microelectronics. Both positive and negative factors were at play. Negative transformation pressure on the firm-level have led to innovations and strategic reorientations. A case in point was Luxor's ABC 80 launched in 1978, which resulted from a reorientation from the saturated home electronics markets to the burgeoning field of computers, becoming one of the first Swedish producers of personal computers. Such reorientations were also made by large corporate groups. Large corporate groups spread risks by having a large number of products in their pipelines at any one time.[2] While early innovators in the new field were typically large incumbents (ASEA, L M Ericsson and Saab) having built up competence in the burgeoning area, a wave of entrant firms emerged to exploit the new technological opportunities. It was observed in chapter 7 that the entry of new computer and measurement equipment firms peaked in 1984 (see Figures 7.2-7.4). From the mid-1980s younger, entrant firms in the hardware ICT industry have contributed greatly to the share of commercialized innovations. By the mid-1980s significant improvements on microelectronic components were made, such as to achieve a rapid decrease in relative prices of electronic components and machinery (Schön, 2006, pp. 32-34, 77-83). At the same time innovation counts and slowed down. This may be understood as a broad shift in the character of development efforts towards less radical improvements and technological rationalizations.

At this point the productivity effects of the microelectronics technology

[2] A statistically significant relationship between negative performance feedback and innovation was not found as regards the large corporate groups. Rather, as a whole innovation activity in these firms may be viewed as driven by institutionalized search for new products. However, chapter 7 found evidence of important strategic reorientations being made in the large corporate groups as a result of transformation pressure.

had stimulated investment in other activities. The impetus of innovation to economic activity also brought momentum to commercial construction activity.

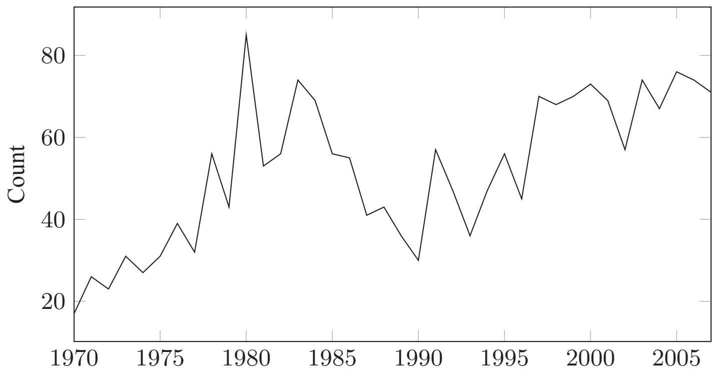
During the 1980s, the development block surrounding ICT technology however faced (and might have helped create) significant imbalances, now of a different character (Freeman & Perez, 1988; Freeman & Louça, 2001; Schön, 2006). Shortage of qualified labor, engineers in particular, became a bottleneck in this process. Other imbalances were institutional and political. Financial deregulations, and deregulations of the telecommunications markets were hastened by economic actors and policy makers. The deregulations of the financial and telecommunication markets were certainly pushed forth by the requirements of the new technologies. The capital markets were deregulated in 1985. The telecommunication market was successively deregulated, but the monopoly of Televerket was however not completely removed until in 1993.

The financial deregulations and the construction boom, were the main ingredients to the Swedish financial crisis of the 1990s. During the crisis the Swedish innovation activity surrounding computers, control systems and industry automation apparatus waned. The crisis of the 1990s thus meant liquidation or a strategic reorientation for many firms. A case in point was Axis Communications, originally selling printer interfaces and print converters, that entered the market of network products.

With the deregulation of telecommunication and financial markets prerequisites for an exuberant expansion in IT and Telecom however were in place. The continued expansion was thus carried by telecommunications, software and infrastructural investments surrounding Internet technologies. The ensuing innovation activity was fuelled by entry of new firms, the vast technological opportunities and the deregulation of the Telecom market. With the infrastructural investments in IT technology new imbalances emerged, now between underperforming components (for instance network processors and switching circuits) in the new technological systems. Innovation activity was to a significant extent aimed towards resolving technological imbalances in Internet and Telecom networks and towards final consumers.

Internationally, as well as in Sweden this expansion was fuelled by financial capital, leading to a 'frenzy' as Carlota Perez has called it. In autumn 2000 the frenzy turned into a downturn, the dotcom bubble. Ericsson and other telecom and IT companies were struck hard, resulting in structure rationalization or bankruptcies. Following the crisis, innovation launches

Figure 8.2: Innovations driven by positive factors.



Count of innovations	1st upswing based on micro-chips, industrial robots and industry automation	Culmination (1983)	Crisis and 2nd upswing based on telecommunications, IT infrastructure and consumer electronics	Culmination (2000) and stabilization
Firm patterns	Large firm dominance	Entry peak in 1984	Entry of firms in IT and Telecom; peak in 1998	Small firm dominance among ICT innovations
Users	Publishing and printing, wood production, general industry		Health care, telecommunications, general industry, final consumers	

and R&D intensity slowed down. Most of the innovations launched during 2000-2007 were launched by small entrant firms in the fields of software, telecommunications, biotechnology or nano-technology.

8.2 Innovation in patterns of long swings and structural cycles.

It is timely to discuss some of the possible corollaries of these findings. The findings of this thesis are largely in consensus with the various perspectives that have stressed the long-term interplay of technological change with economic and social development. A result of this thesis is the observation that the new technologies have evolved by way of solving technical imbalances in surges of roughly 20 years of duration. If these patterns carry further generality, they may be said to be connected with long swings. The pattern of innovations driven by a fundamentally negative transformation pressure on the other hand has for the most part reflected the deeper-lying structural, i.e. economic, social and environmental, problems of the traditional Fordist and oil-based industries. This latter pattern may, if it carries further generality, be said to be connected to the structural cycle of roughly 40 years of duration.

The imbalances that have emerged in the technology shift and those environmental, economic and social imbalances that surfaced in the structural crisis of the 1970s have formed the core of development blocks that have evolved by way of the overcoming of obstacles. Chapter 6 discovered several plausible development blocks in which innovation activity was centered on the resolving of imbalances. Based on the imbalances observed in the ICT industries and renewable energy technologies, one may describe the diffusion of broader sets of new technologies as evolving by way of overcoming *widening* obstacles and imbalances (see Figure 6.6). In the first phases, obstacles have been primarily techno-economical. The development of microelectronics struggled with the "tyranny of numbers" during the 1950s and 1960s. The renewable energy technologies and emission control technologies have all struggled with such obstacles, pertaining to e.g. feasibility and profitability. When these obstacles have been overcome new challenges may emerge in the form of organizational and institutional obstacles. The replacement of old ways of production have often been characterised by inertia and required political and institutional support.[3] For instance, during the period studied, this has certainly been the case as regards the evolution of emission control technologies for automotive vehicles. Moreover, if the new technologies have taken a systemic character, requiring the alignment of components in infrastructural systems, network imbalances have emerged. This was the case in telecommunications and IT infrastructure during the 1990s.

As new technologies have been incorporated into the backbone of society, structural imbalances may emerge, that may cause or contribute to the onset of structural crises. The structural imbalances may then give impetus

[3]This is an aspect stressed by many scholars writing on long waves (e.g. Freeman & Louça, 2001) or structural cycles (Schön, 2006).

to new development blocks centered. The structural imbalances that had emerged in the oil-based and Fordist industries, induced new development blocks at the turn of the structural crisis of the 1970s. Some of the environmental problems could be appeased within the frames of the old development blocks. Other development blocks have struggled with formidable techno-economic obstacles to their introduction. This applies to electric cars and renewable energy technologies in particular.

During structural crises new forces of growth have historically emerged to solve structural imbalances of the mature development blocks. Some of the emerging structural imbalances of the ICT development blocks have been evident in creative response during the period studied. One has been the fact that the Internet and ICT have enabled production of information in vast excess of secure and efficient information processing capacity, in a broad sense. This imbalance has created social, institutional and society wide challenges in the treatment of information, and an ongoing renegotiation of the limits of immaterial property rights and even moral dilemma concerning personal privacy and surveillance. Some of the main structural imbalances still pertain to the oil-based production system and the transition towards renewable energy and material technologies. Towards the end of the period studied, firms developing innovations in "cleantech" have emerged. The period studied in this thesis does not extend far enough to assess to what extent recent economic and energy crises have engendered a large number of innovations in the fields of renewable energy and material technologies or electric cars. There are today substantial obstacles to be overcome, technological, institutional and structural, whose resolution may require radical innovations. The results of this thesis suggests that structural crises may provide strong incentives towards response and problem-solving innovations. Whether and how this applies to the imbalances today, remains to be seen.

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Elektroniktidningen: Sveriges största magasin för elektronikproffs. (1992-2007). Stockholm: Ekonomi + teknik.

Bergsmannen: skandinavisk tidskrift för gruvor, stål- och metallverk, manufakturverk, stål och metaller. (1970-1972). Stockholm: Press information AB.

Bergsmannen med Moderna material SJM-bulletin: skandinavisk tidskrift för gruvor, stål- och metallverk, manufakturverk, stål och metaller. (1972-1977). Stockholm: Press information AB.

Bergsmannen med Jernkontorets annaler: nordisk branschtidning för stål-, metall-, berg- och mineralindustrierna. (1987-2007). Södertälje:

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NTT såg: Nordisk träteknik : Sågverken : en nyhetstidning för skog, sågverk och trävaruhandel. (1999-2002). Stockholm: Mentor Communications.

NTT såg & trä: Nordisk träteknik, Sågverken, Träindustrin. (2003-2007). Lidingö: Mentor Communications

NTT trä: Nordisk träteknik : Träindustrin : en nyhetstidning för trämanufakturindustrin. (1999-2002). Stockholm: Mentor Communications.

Ny teknik. (1970-2007). Stockholm: Teknisk tidskrifts förlag.

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Plastforum Scandinavia. (1977-1992). Helsingborg: Industrifackpress.

Plastforum. (1992-1999). Helsingborg: Aller specialtidningar.

Plastforum Nordica. (2000-2003). Helsingborg: Mentor Communications.

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Teknik i transport. (1989-1992). Täby: Fateco.

Telekom idag: : Sveriges ledande telecomtidning. (1994-). Umeå: North Light Vision.

Textil och konfektion: organ för textil- och konfektionsindustrierna i Sverige. (1970-1971). Stockholm: Stiftelsen Textil och konfektion.

Textil och konfektion med Läder och skor: organ för de svenska textil- och konfektionsindustrierna. (1971-1983). Stockholm: Sveriges textilindustriförbund.

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Transport teknik: maskiner och hantering. (1970-1984). Stockholm: Agrotekniska förlaget.

Transport teknik Scandinavia. (1986-1988). Helsingborg: Industrifackpress.

Verkstäderna: organ för Sveriges verkstadsförening. (1970-1995). Stockholm: Sveriges verkstadsförening.

Verkstäderna: din tidning om modern produktion. (2002-2007). Stockholm: Verkstädernas förlag.

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VVS & energi: organ för VVS-tekniska föreningen. (1983-1989). Stockholm: Förlags AB VVS.

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Denex, annual reports 1983-2007, Bolagsverket.
Diffchamb, annual reports 1987-2007, Bolagsverket.
Doro, annual reports 1982-2007, Bolagsverket.
Ericsson/Sony Ericsson, annual reports 1968-2007, Bolagsverket.
Gambro, annual reports 1977-2004, Bolagsverket.
Geotronics, annual reports 1983-2001, Bolagsverket.
ICL, annual reports 1970-1994, Bolagsverket.
Ifm Electronics, annual reports 1986-2007, Bolagsverket.
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Luxor, annual reports 1970-1991, Bolagsverket.
Malå Geoscience, annual reports 1992-2007, Bolagsverket
Micronic Laser System, annual reports, 1981-2007, Bolagsverket.
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Sieverts, annual reports 1967-2007, Bolagsverket.
Sitek, annual reports 1976-2007, Bolagsverket.
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Spectronic, annual reports 1972-2007, Bolagsverket.
SPM Instrument, annual reports 1970-2007, Bolagsverket.
SRA, annual reports 1970-1983, Bolagsverket.
Standard Radio & Telefon, annual reports 1970-1989, Bolagsverket.
SWEMA, annual reports 1971-2007, Bolagsverket.
Tecator, annual reports 1970-2007, Bolagsverket.
Telemetric, annual reports 1970-2003, Bolagsverket.
UTEC, annual reports 1970-2007, Bolagsverket.

Appendix A

Methodological concerns and critical assessment of SWINNO[1]

In this section some methodological concerns are addressed regarding the SWINNO data. There are in principle two ways to approach the data.

A first approach is to regard the data as illustrative cases. The SWINNO-database contains rich and detailed information, relevant in their own right as examples or illustrations of historical processes. Similarly, industry studies, such as (Greve, 2003a), may be considered relatively unproblematic, as long as the sampling method raises no suspicion of bias towards certain types of firms. Adhering strictly to this point of view would make the restriction on inference from the database unnecessarily severe. The restriction of general claims stems from the question whether innovations reported in trade journals are a special breed of innovation, more important or relevant than other innovations or possessing a certain characteristic. Unless it is possible to show this explicitly, any claim to generality must take into account the remainder of all innovations commercialized and thus address the possibility of a bias or lack of representativity. While stressing that the SWINNO-database is virtually unproblematic as a source of illustrative case studies and in-depth qualitative empirical material, we will try to appraise the boundaries of what general conclusions on innovation in this period that can be made from the database by taking seriously the claim that LBIO-data may say something about innovation activity in general.

The second approach is that the innovations in SWINNO could be con-

[1] This section is identical to parts of Sjöö et al. (2014)

sidered a subset of important innovations within the larger population of all innovations. From this view follows two methodological issues. The subset does not fulfill standard statistical properties in relation to the population of all innovations (Kleinknecht 1993; Kleinknecht et al 2002). This can be remedied by comparing the data with other indicators (van der Panne 2007; Palmberg et al 2000), or by assessing the sensitivity of results with respect to the exclusion of trade journals. The full population of innovation is unknown, if not unknowable, which complicates standard statistical analysis (Archibugi & Pianta 1996, p. 454).

The SWINNO-database is a selection of significant innovations. The interviews with editors revealed support for this view. Furthermore, a comparison with the Wallmark and McQueen (1991) and Svenska Institutets publication Svenska Innovationer indicates a large coverage (74% and 86% respectively) of the innovations that in retrospect turned out to be highly important. Thus, the SWINNO-database is better understood as a sample of significant innovations than a sample of innovations in general, and we have reasons to expect a reasonable coverage rate of important innovations. This however does not exempt the SWINNO-database from the methodological considerations dealt with in previous studies.

There are four issues that have been raised in the literature as regards representativity and validity of LBIO data. First, there is a possibility that LBIO may overestimate the number of domestic innovations if based on product announcements which, as a matter of fact, not always accurately report the developing firm (Van Der Panne 2007). As the SWINNO-database does not rely on product announcements at all, but rather edited articles in which the developing firm is mentioned as such, this problem has no bearing on SWINNO. Second, it is possible that trade journals report innovations from large companies to a lesser degree than innovations from small companies. This may be the case due to the potential lack of incentives for larger companies to advertise new products through public channels (Coombs et al 1996, p. 405; Santarelli & Piergiovanni 1996). Large firms may also be more likely to have their products recognized by journals, (Acs & Audretsch 1990; Tether 1996). Edwards & Gordon (1984) raised concerns about the opposite direction of bias, as small firms may lack the necessary resources to produce press releases. This direction of bias is however not clear. This possible bias in one way or the other, however concerned data assembled on the basis of new product announcements (relying heavily on press releases), whereas SWINNO is based on edited articles, making such bias unlikely. In a comparison of SFINNO data with CIS data, Van Der Panne

(2007) and Palmberg et al (2000) found no bias in any direction with respect to firm size. Third, bias may be introduced by changes in publication policies of trade journals and public relation policies of firms (Kleinknecht et al 2002, p. 116). It is for instance possible that trade journals report differently over time about innovations, due to changes in publication policies. The selection of journals as well as the editorial policies are discussed in the below sections. The general validity of SWINNO is supported by the consistency over time as well as between journal when it comes to publication policy for innovations. More specific issues and the representativity of SWINNO should be assessed as an empirical question in comparison with other indicators.

A Comparison with Swedish CIS data

Similar to Palmberg et al (2000) and Van Der Panne (2007), a comparative analysis is carried out for LBIO and CIS, here SWINNO and CIS 1998-2006. Due to methodological differences between SWINNO and CIS data the comparison serves as a basis for discussion, rather than a direct test for bias.

The size distribution of firms and the distribution of the number of innovations across product groups can be compared with Swedish CIS data for the benchmark years of 1998-2000, 2002-2004 and 2004-2006. The comparisons are made in terms of the relative frequency of innovating firms in employment classes and sectors. As the CIS data do not concern the number of innovations, but rather the number of innovating firms (both process and product innovations) the latter form the basis of comparison. Also, the basis of comparison is the number of firms engaging in product innovation.

For a comparison of the size of innovating firms we are focusing on the CIS of 1998-2000 as the later surveys present only broad employment categories. Even in CIS 1998-2000 the smallest class of enterprises, with less than 10 employees, is not surveyed.

A discrepancy probably arises from the methodological differences. The self-reported surveys make CIS picks up innovations which are new to the firm, but to a lesser degree new to the market, whereas SWINNO only captures significant innovations.

The most striking difference is that CIS 1998-2000 reports a total num-

Table A.1: Comparison of the size distribution of innovating firms, CIS and SWINNO 1998-2000.

Firm size: employees	CIS 1998-2000	Share (%)	Counter-factual	SWINNO 1998-2000	Share (%)	0-9 excluded
0-9	na		38	102	38	
10-19	2,171	42	26	29	11	19
20-49	1,588	31	19	44	17	29
50-99	517	10	6	15	6	10
100-499	721	14	9	37	14	24
500-	185	4	2	39	15	25
Total	5182			266		

ber of innovations that is about twenty times higher than SWINNO for the same years. The difference is actually even higher since CIS does not include the smallest firms which, in SWINNO, provide 38 per cent of all innovating firms in 1998-2000. Making the counterfactual assumption that an equally big share, for the smallest firms, would have been reported by CIS if these firms were included in CIS, would add almost 3,200 to the CIS number of innovating firms and increase the differential to more than 30 times. It is clear that CIS and SWINNO deal with innovations of different sorts.

Table A.1 shows the numbers of innovating firms in CIS and SWINNO as well as the distribution on firm sizes - including with the counterfactual assumption that CIS would have relatively the same share of firms with less than 10 employees. However compared, the difference remains and consists in a much higher share of innovating firms among the larger firms, and a smaller share of the firms with 10-19 employees, in SWINNO. Had it not been for the substantial share, 38 per cent, among the smallest firms with less than 10 employees, one would have suspected that SWINNO is biased towards big enterprises. Now, a conclusion is that the journals on which SWINNO is based, neither neglects big nor small firms. The difference in numbers could be interpreted as a reflection of the self-reporting firms in CIS whereas the journals have recorded the more significant innovations in SWINNO. Whether the distribution also is fairly representative is, however, another question and only by continuing the comparison we can at least get a reasonable picture of the representativity and validity of SWINNO.

Another aspect of the distribution of innovation is how they are allocated between sectors. If we presume that the propensity to innovate is related to the level of technology, then we would, irrespective of the difference in numbers, expect a correlation between the sectoral allocation of innovations in CIS and SWINNO. Tables A.2 - A.3 show the distribution of innovating firms across sectors according to three different editions of CIS, and the corresponding years of SWINNO. Overall, the distribution is quite broad in both measures. One difference catches the eye, and that is the relative share of machinery and equipment (SNI 29) and ICT industries (SNI 30-33) which is 10 percentage points, or more, higher in SWINNO than in CIS. It could be that these sectors attract more interest from the journals but since these are selected as representative for all sectors it could as well indicate that machinery and ICT provide relatively more significant innovations. The correlation between sectors is, however, rather close between CIS and SWINNO, as can be seen from the bottom line in Tables A.2 - A.3. In conclusion, given that the innovative firms are several times more in CIS than in SWINNO which is taken as an indication that the latter contains the more significant innovations, we find no seriously disturbing differences in the distribution, neither across firm sizes nor across sectors. There are some questions marks which remain for further research to validate.

Table A.2: Sectoral distribution of innovating firms in CIS and SWINNO 1998-2000.

SNI	CIS 1998-2000	(%)	SWINNO 1998-2000	(%)
10-14			1	0.40
15-16	174	4.02	4	1.58
17-19	72	1.67	3	1.19
20	97	2.24	6	2.37
21-22	231	5.34	3	1.19
23-24	112	2.59	6	2.37
25		0.00	9	3.56
26		0.00	3	1.19
27-28	333	7.70	20	7.91
29	484	11.19	30	11.86
30-33	335	7.75	42	16.60
34-35	102	2.36	8	3.16
36-37	136	3.15	0	0.00
40-41	49	1.13	0	0.00
45		0.00	3	1.19
51	1463	33.83	30	11.86
60-64	312	7.22	9	3.56
65-67	145	3.35	0	0.00
70		0.00	4	1.58
72		0.00	30	11.86
73		0.00	18	7.11
74	279	6.45	24	9.49
Total	4324		253	
Correlation		0.599*		

Table A.3: Sectoral distribution of innovating firms in CIS and SWINNO 2002-2004 and 2004-2006.

SNI	CIS 2002-2004	(%)	SWINNO 2002-2004	(%)	CIS 2004-2006	(%)	SWINNO 2004-2006	(%)
01-05	0	0	1	0.42	0	0	1	0.36
10-14	4	0.14	1	0.42	4	0.16	0	0
15-16	116	4.09	3	1.27	79	3.16	3	1.08
17-19	39	1.37	1	0.42	44	1.76	2	0.72
20	42	1.48	3	1.27	43	1.72	5	1.8
21	30	1.06	6	2.53	31	1.24	6	2.16
23	0	0	0	0	4	0.16	0	0
24	56	1.97	6	2.53	49	1.96	4	1.44
25	56	1.97	5	2.11	43	1.72	4	1.44
26	23	0.81	0	0	20	0.8	1	0.36
27	5	0.18	6	2.53	17	0.68	7	2.52
28	124	4.37	9	3.8	174	6.95	13	4.68
29	207	7.29	28	11.81	186	7.43	34	12.23
30-33	120	4.23	27	11.39	141	5.64	32	11.51
34-35	80	2.82	10	4.22	85	3.4	9	3.24
22+36-37	150	5.29	5	2.11	153	6.12	5	1.8
40-41	12	0.42	0	0	13	0.52	0	0
50-52	818	28.82	26	10.97	520	20.78	40	14.39
55	0	0	0	0	0	0	1	0.36
60-63	80	2.82	0	0	85	3.4	0	0
64+72	338	11.91	34	14.35	286	11.43	30	10.79
65	19	0.67	0	0	35	1.4	0	0
66	12	0.42	0	0	12	0.48	0	0
67	18	0.63	1	0.42	25	1	0	0
73	40	1.41	27	11.39	40	1.6	31	11.15
74	449	15.82	39	16.46	413	16.51	50	17.99
Total	2838		237		2502		278	
Correlation		0.695^{***}				0.828^{***}		

Robustness tests

One may suspect that changes in publication policies and differences in the publication policies across trade journals have influenced the general results of SWINNO. If the results are not significantly sensitive to the inclusion or exclusion of particular journals, then it is possible to say that the results are insensitive to hypothetical changes in publishing policies of particular journals. The underlying idea is that there is an overlapping between the journals and the question is if this is sufficient to compensate for the hypothetical loss of one journal.

For a formal analysis of the robustness of our results to the included trade journals, a simple test has been constructed. The underlying principles can be summarized:let any time series or descriptive statistic, a vector X over some index (e.g. sectors or time) be composed by a set of components i , in our case journals, which contribute to the statistic according to $X = X_1 + X_2 + \ldots + X_n = \sum_{i=1}^{n} X_i$ If the overall results are robust, removing a journal should not significantly alter them. Certainly, removing a journal will decrease the total count, but it should not alter the distribution over the relevant domain. By successively removing journals and comparing the results one may assess the robustness of the series. We proceed by examining the correlations of all time series or descriptive statistics that are possible to generate by removing all combinations of journals against their respective remnants.[2] We may say that the statistics are robust to arbitrariness in the choice of journals if the average correlation coefficient is significant on the 90%-level. The acceptance of a wider margin of error than with the conventional 95% is due t o the expectation that there are some differences, when a journal is excluded, and the accordingly higher risk of a type 1 error (rejecting what is true). As the calculations are tedious in the second case (with 16 journals we must examine 136 possible time series or descriptive statistics), a programming code has been written and carried out in statistical software R.

The tests consider a) number of innovations per year of commercialization in total and by sector, b) the number of innovations by sector, c)

[2]Since the correlation of X with $X - X_i$ clearly will introduce bias in the estimates it is more sensible to examine whether components X_i are correlated to the remainder $X - X_i$. In principle, a good picture could be given by removing only one journal. A more ambitious and complete approach however is to test the results for the removal of any number and combination of journals.

Table A.4: Results from robustness analysis. Figures presented are the average Z-test in bivariate Poisson regressions and Pearsons correlation coefficients (r).

	Z	R
Count of innovations per sector	62.02***	0.86***
Commercialized innovations per year, total	1,37*	0,11
Commercialized innovations per year, SNI		
15	0.22	0.03
20	-0.02	0.01
21	1.26	0.2
24	-0.43	-0.07
25	2.42***	0.32**
26	0.64	0.11
27	0.2	0.04
28	1.46*	0.18
29	5.63***	0.47***
30	0.25	0.04
31	0.42	0.07
32	1.55*	0.16
33	-0.81	-0.09
34	-0.07	0
35	0.14	0.02
36	0.85	0.1
72	5.47***	0.5***

Note: *, p<0.1; **, p<0.05; ***, p<0.01.

the number of innovations by employment class in total and by sector. The results are presented in Tables A.4 and A.5.

The total number of innovations per year of commercialization follows a distinct pattern with an increase in the total count 1975-1983, a sharp fall until the mid-1990s, and a subsequent increase in the 1990s. In the formal test, these results are modestly robust to changes in the journals. The average correlation is 0.11 ($p > 0.10$) but the average Z-test from bivariate Poisson regressions is 1.37 ($p < 0.10$). It is known that correlation is sensitive to outliers why we can conclude that for some sectors results are sensitive for change in the editorial policy of a particular journal but the overall pattern is robust.

Moreover, it is found that machinery innovations (29), fabricated metal innovations (28), plastic and rubber innovations (25), telecommunications

(32) and software innovations (72) are insensitive regardless of the journals one chooses. Innovations in these product groups not only make out a substantial share of all innovations but also contribute significantly to the variations over time. Thus, one may conclude that the aggregate pattern of innovations is a generic result of the database, not pertaining to the idiosyncrasies of any one trade journal.

Another important result of the SWINNO-database concerns the distribution of innovating firms. The database allows for discrimination of firms according to 16 employment classes. A majority of the innovations were developed by firms with less than 200 employees. We know however that this is not true of all product groups, and we know from the literature that patterns of innovation differ across sectors. These aggregate results are very robust to exclusion of an arbitrary number and combination of journals (see table 25). When ordered by product groups, the distribution is robust ($p < 0.10$) for three fourths of the product groups. The exceptions are product groups of which most were robust when it comes to number of innovations over time, why we may infer that the editorial interest for the product groups was reasonably stable. The remaining exception is foodstuff (SNI 15) which actually is present in a limited number of journals and that would motivate a further check with other sources.

Table A.5: Results from robustness analysis. Count of innovations per employee class, in total and by product group. Figures presented are the average Z-test in bivariate Poisson regressions and Pearsons correlation coefficients (r).

Count of innovations per employee class (0-16) of the firm	47.24***	0.96***
Count of innovations per employee class (0-16) of the firm, by SNI	Z	R
15	0.11	0.03
20	3.03***	0.32**
21	3.57***	0.41***
24	1.36*	0.15
25	1.13	0.16
27	1.47*	0.18
28	3.61***	0.38***
29	0.46	0.07
30	4.59***	0.38***
31	2.12**	0.28**
32	-0.75	-0.12
33	1.49*	0.23*
34	4.27***	0.4***
35	4.63***	0.5***
36	4.51***	0.43***
72	2.23**	0.28**

Note: *, $p<0.1$; **, $p<0.05$; ***, $p<0.01$.

Appendix B

Industrial nomenclature

Table B.1: Industrial nomenclature, description and code in SNI 2002.

SNI 2002	Text
150	Food products and beverages
160	Tobacco products
170-190	Textiles, wearing apparel and leather
200	Wood and wood products, except furniture
210	Pulp, paper and paper products
220	Publishing, printing and reproduction of recorded media
230	Coke, refined petroleum & nuclear fuel
241-242	Basic chemicals, pesticides and other agro-chemical products
243	Paints, varnishes and similar coatings, printing ink and mastics
244	Pharmaceuticals
245-247	Other chemical products (including soap and detergents etc and man-made fibres)
251	Rubber products
252	Plastic products
260	Other non-metallic mineral products
270	Basic metals
281	Structural metal products
282-283	Metal containers; central heating radiators; steam generators
284-285	Forming and coating of metals; general mechanical engineering
286	Cutlery, tools and general hardware
287	Other fabricated metal products
291	Machinery for the production and use of mechanical power, except aircraft,
29210	Furnaces and furnace burners
29220	Lifting and handling equipment
29230	Non-domestic cooling and ventilation equipment
29240	Other general purpose machinery n.e.c.

293	Agricultural and forestry machinery
294	Machine-tools
29510	Machinery for metallurgy
29520	Machinery for mining, quarrying and construction
29530	Machinery for food, beverage and tobacco processing
29540	Machinery for textile, apparel and leather production
29550	Machinery for paper and paperboard production
29561	Machinery for plastic and rubber processing
29569	Other special purpose machinery n.e.c.
296	Weapons and ammunition
297	Domestic appliances n.e.c.
300	Office machinery and computers
311	Electric motors, generators and transformers
312	Electricity distribution and control apparatus
313	Insulated wire and cable
314	Accumulators, primary cells and primary batteries
315	Lighting equipment and electric lamps
316	Electrical equipment n.e.c.
321	Electronic valves and tubes and other electronic components
322	Television and radio transmitters and apparatus for line telephony and line
323	Television and radio receivers, sound or video recording or reproducing apparatus
331	Medical and surgical equipment and orthopaedic appliances
332	Instruments and appliances for measuring, checking, testing, navigating and other
333	Industrial process control equipment
334	Optical instruments and photographic equipment
335	Watches and clocks
341	Motor vehicles
342	Bodies (coachwork) for motor vehicles; trailers and semi-trailers
343	Parts and accessories for motor vehicles and their engines
351	Building and repairing of ships and boats
352	Railway and tramway locomotives and rolling stock
353	Aircraft and spacecraft
354	Motorcycles and bicycles
355	Other transport equipment n.e.c.
361	Furniture
362-366	Manufacture n.e.c
370	Recycling
640	Post and telecommunications
720	Computer and related activities
730	Research and development
740	Other business activities

Appendix C

Network analysis

Formal definitions

An innovation flow matrix can be understood as a directed weighted network with the sectors as ‘vertices’ (industries) and with the number of innovations between industry i and industry j as its ‘edges’. A network, or a graph, is formally defined as $\Gamma = (V, E)$, where V is a set of vertices and E is a set of edges $E \subset V \times V$. With N vertices, the network is represented by the so-called adjacency matrix, denoted A whose elements are a_{ij}. The standard case is an unweighted and undirected network, which means that $\forall_{ij}, a_{ij} \in [0, 1]$ and $a_{ij} = a_{ji}$. The innovation flow matrix is however both weighted and directed. For a directed weighted network, each edge from vertex $i \in V$ to another vertex $j \in V$, has a weight $a_{ij} \in \mathbb{R}_{+}$. Then, we may define the out-strength, in-strength and total strength of a vertex i according to Table C.1. This corresponds thus to the total number of innovations supplied, the total number of innovations used and the total number of innovations supplied or used, respectively.

The results from the communities can be summarized similarly as in Table C.1 by calculating the out-strength and in-strength for a vertex i within its community c_i.

Table C.1: Summary of concepts and formal definitions pertaining to network analysis.

Description	Formal Definition
Out-strength of vertex i	${k_i}^{out} = \sum_j a_{ij}$
In-strength of vertex i	${k_i}^{in} = \sum_j a_{ji}$
Total strength of vertex i	$k_i = \sum_j a_{ij} + \sum_j a_{ji}$
Modularity for undirected networks (Newman 2006)	$Q^{un} = \frac{1}{2k} \sum_{ij} [a_{ij} - \frac{k_i}{2k}] \delta_{c_i c_j}$ where $\delta_{c_i c_j} = 1$ if $c_i = c_j$ else 0
Modularity for directed networks (Leicht and Newman 2008)	$Q^{dir} = \frac{1}{k} \sum_{ij} [a_{ij} - \frac{k_i^{out} k_j^{in}}{k}] \delta_{c_i c_j}$
Out-strength of vertex i within its community c_i	$\sum_j a_{ij} \delta_{c_i c_j}$
In-strength of vertex i within its community c_i	$\sum_j a_{ji} \delta_{c_i c_j}$

Spectral bisection algorithm

The detection of community structures in the Innovation Flow Matrices is carried out through a fast greedy algorithm and two spectral bisection algorithms. The first has been implemented with package igraph in software R. The second two have been implemented following the steps (cf Leicht & Newman 2008): The modularity matrix B is calculated with elements $B_{ij} = A_{ij} - (k_i^{in} k_j^{out})/k$. We find the eigenvector v^* corresponding to the maximum eigenvalue λ_{max} of the symmetric matrix $B + B^T$ and subsequently assign vertices to the community α if the sign of corresponding element of the eigenvector v^* is positive and to the community β if the sign is negative. Given this first bisection, the partition is fine tuned in the following way (cf Newman 2006): we find the vertex that if moved to the other group will give the biggest increase in the modularity of the complete network, or the smallest decrease if no increase is possible. With the constraint that each vertex is moved only once, we move all vertices and then examine set of intermediate states to find the state that has the greatest modularity. Departing again from this new state the process is repeated until no further improvement in the modularity results. The communities are further subdivided by repeated bisection. The change in modularity ΔQ of the entire network when a community g within it is subdivided is given by:

$$\Delta Q = \frac{1}{2k}\sum_{ij\in g}(B_{ij}+B_{ji})\frac{(s_i s_j+1)}{2} - \sum_{ij\in g}(B_{ij}+B_{ji}) \\ = \frac{1}{4k}s^T(B^g+(B^g)^T)s \tag{C.1}$$

where $B^g_{ij} = B_{ij} - \frac{1}{2}\sum_{k\in g}(B_{ik}+B_{ki})\delta_{ij}$. The change in modularity can thus be maximized in the same way by finding the eigenvector corresponding to the maximum eigenvalue of the symmetric matrix $B^g + (B^g)^T$. The bisection stops when no improvement in the ΔQ can be found.

The programming code is available from the author upon request.

Appendix D

Additional tables, performance feedback tests

Prerequisites for the tests of performance feedback in chapter 7 is that returns on assets is independent of the firms' innovation launches. Returns on assets may be dependent on previous and current innovation activity through a positive effect on sales. The possibility was examined by running a test for reverse causality found in Table D.1. It is also possible that returns on assets might be negatively affected by increased R&D costs, which would lead to spurious results. Due to inconsistency in accounting methods, R&D costs could not be systematically collected.[1] When presented current R&D costs typically entered the accounts as depreciation of immaterial assets. Since however both profits before and after depreciation were collected it is possible to compare whether the results are similar before or after taking account of depreciation. This comparison is found in Table D.2. None of these tests showed indications of issues with reverse causality or risks of spurious results.

[1]Moreover, there are definition problems. Glete (1983)for instance warns about poor quality in R&D costs in ASEA's financial accounts.

Table D.1: Tests of impact of innovation of returns to assets (net of depreciation). Panel fixed effects regression.

AGE	0.0027 [0.0071]
AGE2	0.0000 [0.3980]
Innovation launches	-0.010 [0.007]
Lag1	-0.007 [0.007]
Lag2	-0.007 [0.007]
Lag3	-0.007 [0.007]
ΔS	0.072^{***} [0.012]
Lag1	0.067^{***} [0.017]
Lag2	0.040^{***}[0.012]
Lag3	0.036^{***} [0.011]
Obs	1069
Firms	46[a]
R^2	0.08

*, p<0.1; **, p<0.05; ***, p<0.01. Standard errors in brackets.

[a] Consistent series for sales growth for ASEA/ABB were not available.

Table D.2: Poisson panel fixed effects regression. Comparison between returns before and after depreciation.

Model	Before depreciation	After depreciation
AGE	-0.049^{***} [-0.015]	-0.063^{***} [0.015]
AGE2	0.0001 [0.000]	0.0002^{***} [0.000]
$\Pi - L$	-0.607 [0.630]	-1.011^{*} [0.549]
Lag 1	0.240 [0.672]	0.521 [0.644]
Lag 2	-1.547^{**} [0.683]	-1.613^{***} [0.676]
Lag 3	0.475 [0.7337]	1.086 [0.069]
Log-Lik	-463.50	-565.54
Firms	46	47
Obs	1147	1231

*, p<0.1; **, p<0.05; ***, p<0.01. Standard errors in brackets. Returns before depreciation not available for Ericsson.

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