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ELINKEINOELÄMÄN TUTKIMUSLAITOS
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY
Lönnrotinkatu 4 B 00120 Helsinki Finland Tel. 358-9-609 900
Telefax 358-9-601 753 World Wide Web: http://www.etla.fi/

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Tuomo Nikulainen

A HISTORICAL PERSPECTIVE ON PATENTS AND INDUSTRY GROWTH IN FINLAND – CONNECTIONS AND LAGS

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Corresponding author: Tuomo Nikulainen, Etlatieto Ltd. / ETLA (The Research Institute of the Finnish Economy), Lönnrotinkatu 4 B, 00120 Helsinki, Finland. Phone: +358 50 548 1336. Fax: +358 9 601753. E-mail: tuomo.nikulainen@etla.fi

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ABSTRACT: This paper aims to establish how the innovative activity in Finland has changed over time in the transition from a resource-driven economy to a knowledge-driven economy. The paper first takes a historical perspective on innovation and industrial activity in Finland through a descriptive analysis. The aim is to identify technological trends in both specific technological areas as well as in different industries. Patent data provides a long time-series of innovative activity from 1842 to 2005 covering 164 years overall. This data is complemented with industry data from 1948 to 2007. The industry data allows a comparative descriptive analysis between the main industries and their respective technological development.

The descriptive analysis is complemented with a statistical analysis, in which the interaction between growth in industrial volumes and growth in patent stock is empirically examined taking into account the industry specificities and lag-structures. This approach reveals whether patenting activity, used to approximate innovative activities, can be used to predict the growth of industrial activity. This aspect has received surprisingly little attention in prior research. The regression analyses show that there is a positive connection between industry growth and patent growth. In addition, the patent growth lags, both backward and forward in time, are positively connected to the industrial growth. This finding suggests that there might exist a positive cycle where innovation induces industry growth, which in turn induces innovative activities. Furthermore, patent growth seems to have a weak positive impact on industry growth with a lag of 13 years. This indicates that patent growth might provide weak signals of future industry growth.

Keywords: patents, industry growth, lags, technological change

JEL: L60, O11, O14, O33

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1. INTRODUCTION

The industrial revolution in the Western hemisphere in the 18th and 19th centuries was the starting point for the rapid technological development that has continuously driven economic growth at an ever increasing pace. The industrial revolution occurred in different countries in different periods and in different forms based on national competences and knowledge flows between nations (von Tunzelman, 1995). The industrial revolution started a period of increased economic growth where technological change is seen as one of the key drivers of this development (Sokoloff, 1988). It is important to view technological change as a process that should be observed over a long period. By understanding the role and nature of technological change, it is possible to gain further insight into long-term industrial evolution and create methods for forecasting potential future industrial trajectories.

As mentioned, technological change has almost universally been seen as the key driver for economic growth (e.g. von Tunzelman, 1995; Andersen, 1999; Jungmittag, 2004). Sometimes technologies yield instant productivity gains, but more often the impact comes in long waves (Andersen, 1998), which are often based on the emergence of a general purpose technology such as the steam engine, electricity, mass production and ICT (Lipsey et al., 2005). The discussion of long waves provides a motivation for this paper, as the impact of technologies on economic activity is seen as a cyclical process. These long cycles, which affect the development of productivity, for example, consist of shorter cycles related to the internal development of the technology (Perez, 1983), which in turn are tightly related to the emergence and development of industrial activity utilising these technologies.

The cycles are seen to have an impact on industrial activity, but it should be noted that there have been and still are significant technological gaps between industrialized countries (Fagerberg and Verspagen, 2002). In the lagging countries, in particular, innovation policy has become one of the main instruments to fill the technological gap, while in the forerunner countries it is mainly implemented to sustain a leading position (von Tunzelman, 1995). These innovation policies have had a significant impact on the organisation of R&D and the existence of national systems of innovation (Lundvall, 1992; Freeman, 1995). One of the goals in national innovation policy is to identify the most promising areas where public intervention can have an impact on potential market inefficiencies (e.g. lack of funding), but at the same time the goal is to ensure that the policies are diversified enough to allow overall technological development even in areas which are not expected to spawn the next general purpose technology.

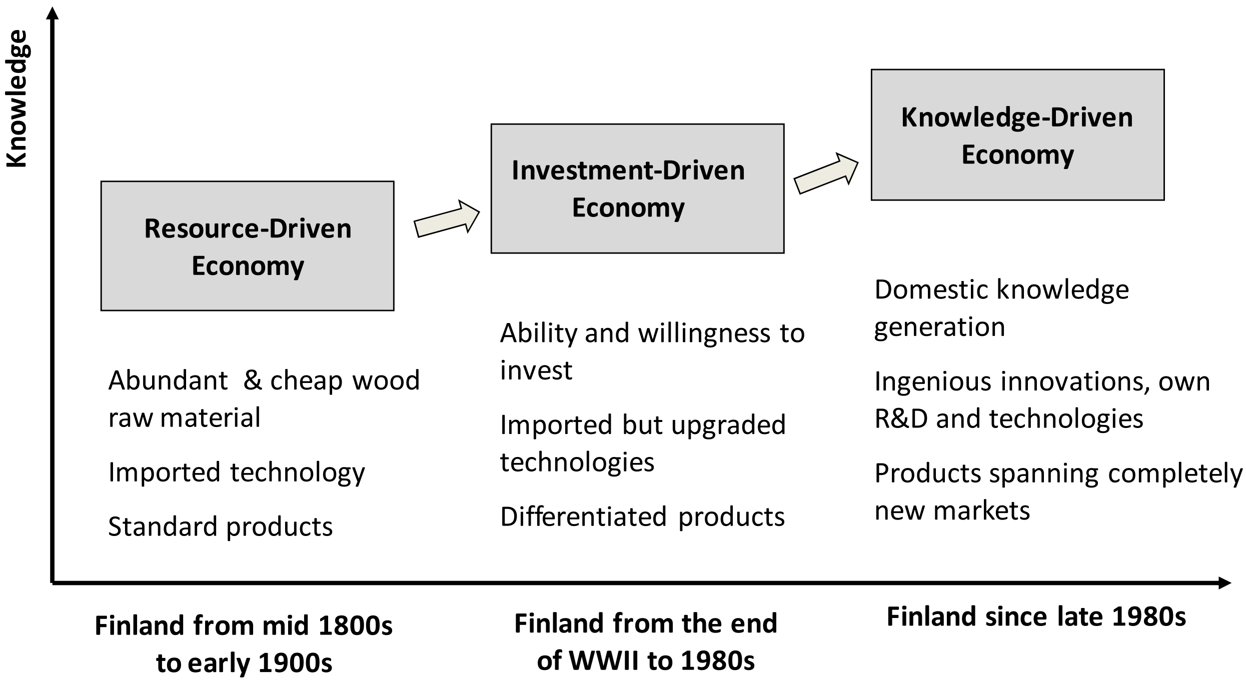
Motivated by the need to understand the cyclical nature of technological change for the purpose of designing and implementing efficient innovation policies, this paper establishes a connection between technological development and industry growth. By using both descriptive and statistical methods this paper answers the following questions: Is there a connection between industry growth and innovation? And can innovation-related indicators predict the future growth of an industry?

The structure of the paper is as follows: in Section 2 the industrial development of Finland is briefly discussed to provide a context for the analysis; in Section 3 the data and methodological aspects are discussed; in Section 4 the descriptive analysis of technological development in different technologies and in specific industries is presented; in Section 5 the statistical analysis focuses on the empirical examination of the interaction between the growth of industry production volumes and the growth in patenting activity, and attempts to identify the lag-structure between the two components; and in Section 6 a synthesising discussion and conclusions are presented including suggestions for future research.

2. INDUSTRIAL DEVELOPMENT IN FINLAND

The context of this analysis is Finland where industrial development has seen a rapid change from a resource-driven economy to a knowledge-driven economy. To understand the interaction between technological change and industrial growth in the Finnish economy, we need to understand this transition process especially in the technological perspective. In Figure 1 the different stages of development are illustrated both in time and in knowledge intensity.

Figure 1. Stages of industrial and economic development in Finland



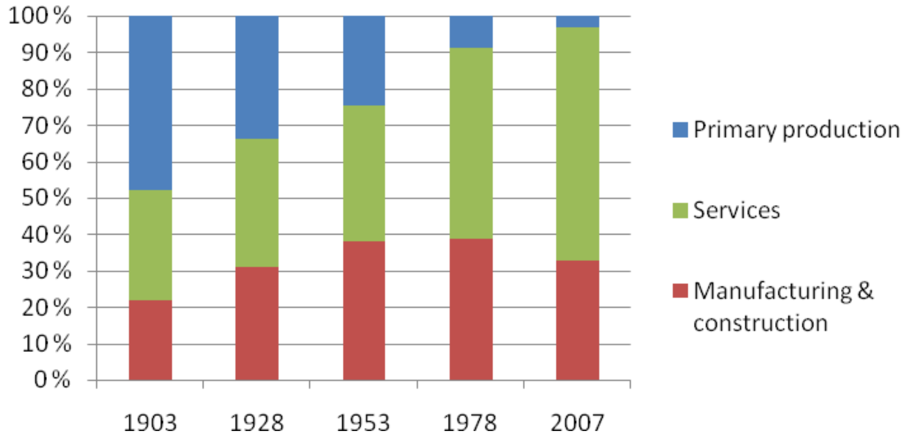
Source: Dahlman et al. (2006)

Finland was a late-comer in the industrial revolution, and the real impact on the structure of industry started to show as late as in the late 19th century compared to many other Western countries where the change happened roughly one hundred years earlier. From the beginning of the Finnish industrial revolution until the early 20th century the Finnish manufacturing industry was driven by abundant and cheap wood raw material, which facilitated the development of the forest and paper industry. The technological development was mostly based on imported technologies and resulted in the production of standard products for export. From the 1950s until 1980s Finnish industries were willing and able to invest in new facilities and technologies by importing while, at the same time, upgrading these technologies. This investment-driven phase yielded further growth, and exports were gradually driven towards more differentiated products. These investments in technologies created a knowledge base that pushed Finland towards the next and current phase of development – a knowledge-driven economy. Since the late 1980s Finnish industries have been driven by domestic knowledge generation yielding indigenous innovations through significant investments in R&D and technologies. This has resulted in the creation of completely new products for new markets. The most notable development has been the rise of the ICT industry that has significantly diversified the range of exported products.[1]

[1] For a well illustrated overview of the transformation of Finland from a resource-driven economy to a knowledge driven economy see Dahlman et al. (2006).

The timeframe in the current paper is from 1842 to 2007, and varies from analysis to analysis with the availability of reliable data. The main focus in the analysis is on the manufacturing industries, as they are usually the key drivers of economic growth through domestic employment and export activity, especially in a small open economy such as Finland. The importance of manufacturing industries in Finland has been constantly significant especially when compared to other sectors (see Figure 2).

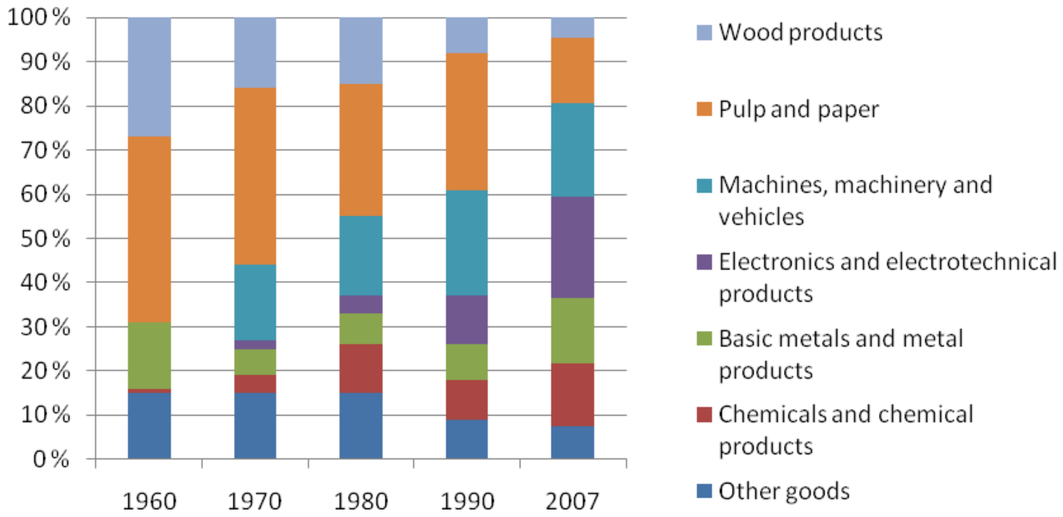
Figure 2. GDP by sectors in Finland (%)



Source: Hjerppe (1988) and Statistics Finland

It is clear that manufacturing has remained an important cornerstone of the Finnish economy as is the case in many other countries. The service sector has increased its significance during the last hundred years substituting the dominant role of primary production in the beginning of the 20th century. Interestingly, the share of manufacturing of the total GDP has remained close to 30% in Finland from the 1950s onwards, while in many other OECD countries the share has declined to around 20% thereby indicating a diminishing role of manufacturing (Dahlman et al., 2006). While the role of manufacturing industries has remained significant, their production activities have changed radically from standard products to higher value-added products as illustrated in Figure 3 through the changes in exported goods.

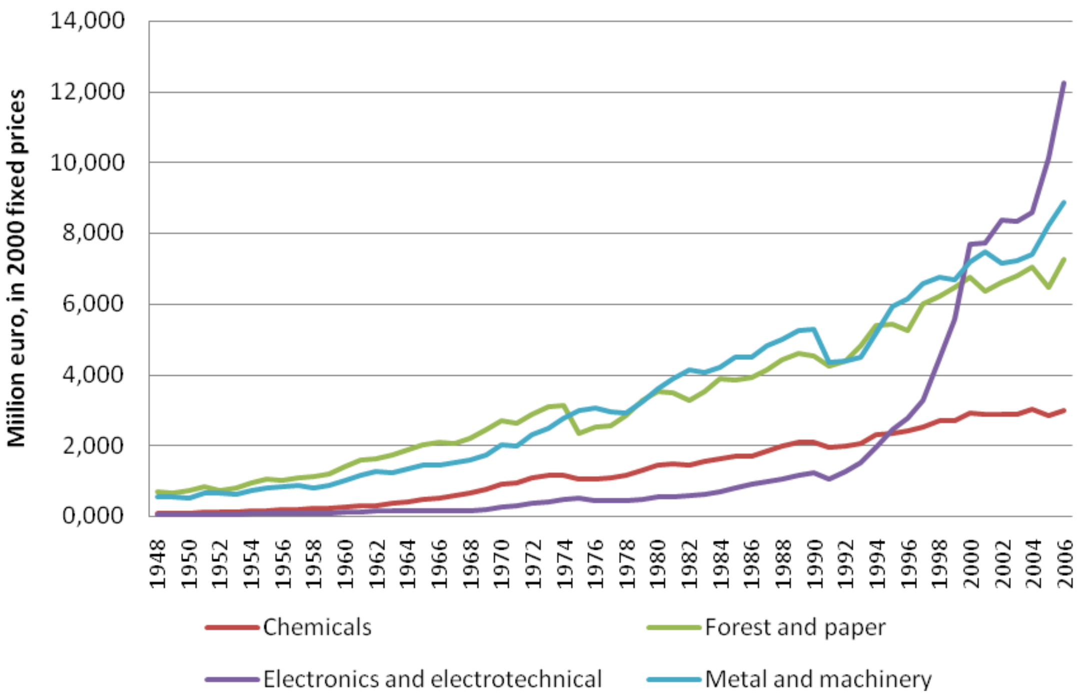
Figure 3. Exports of goods by industry sector in Finland (%)



Source: Statistics Finland and National Board of Customs

The changes in exported goods show that Finnish industries produced standard products such as paper and basic metal in the 1960s, but recent years have witnessed a change in the structure of exports towards higher value-added products such as electronics and machinery. This rapid structural change is a result of technological changes in industries that earlier relied on imported technologies and have since moved on to producing higher value-added goods, a phenomenon coinciding with the emergence of ICT. A similar story emerges when the development of industry volumes is presented. Figure 4 illustrates the industry production volumes of the most significant industries in Finland.

Figure 4. Industry production volume for the main manufacturing industries 1948-2006



Source: Statistics Finland

The development of the main manufacturing industries shows a steady growth for the more traditional industries (i.e. metal and machinery, forest and paper, and chemicals). The electronics and electrotechnical industry has experienced a rapid growth mostly due to the developments in the ICT sector. The trends also show the external shocks in 1970's (energy crisis) and in the early 1990's (global economic slow-down and national depression due to financial mismanagement and collapse of the Soviet exports). The latter shock also started the rapid restructuring of Finnish industries and was the starting point for the development of the ICT sector.

The aim of this paper is to analyse the role of innovative activity in the Finnish industrial growth through quantitative methods. The focus is especially on the use of patent statistics in predicting the industry growth. A more detailed story of the main industries and the technologies affecting them is presented in descriptive manner in Vuori and Ylä-Anttila (1992), and in Dahlman et al. (2006) . The descriptive analysis in the current paper focuses on the technological change measured through patents both on the technology level as well as on the industry level. In the latter part of the paper the focus turns towards industry growth and especially on the connection between the growth of industry production volume and the growth in patenting. Through a statistical regression analysis the lag-structure between the two data series is also illustrated.

3. DATA AND METHODOLOGY

3.1. Data sources and construction of data sets

To analyse the evolution of innovative activities in Finland and its connection to industry growth, this paper uses two different data sets. The innovative activity is measured and approximated through patent statistics and the industrial activity through data on industry production volumes. While the patent data is used in the descriptive analysis in Section 3, the industry data on production volumes is included in the statistical analysis in Section 4.

3.1.1. Patent data

The source of the patent data is the EPO Worldwide Patent Statistical Database (PATSTAT) created by the European Patent Office (EPO) on behalf of the OECD.[2] PATSTAT covers over 80 countries and allows the analysis of longer time-series than is usually used in economics research. For this paper this means that Finnish patent data from 1842 to 2005 can be analysed.[3] In existing research it is common practice to use only national (e.g. European (EPO) or US) patents due to difficulties in comparison between the patent systems. In this paper this dilemma is solved by using patent family data.

3.1.2. Industry data

Contrary to the time-series of patent data, the construction of industry data for roughly 150 years proved to be a more challenging exercise. The original goal was to create a time-series for the main industries in Finland starting from 1860. However, when compiling these data sets, the available data sources proved to be too aggregated for proper analysis. Thus the focus, when industry data is used, is on the period from 1948 onwards, since for this period (1948-2007) more disaggregated industry data is available. This allowed the analysis of more modern industries such as the electronics and electrotechnical industry. The industry production volume data series is presented in fixed prices with respect to the year 2000 (see Figure 4 above).

3.2. Methodological aspects

Before going into the actual analysis it is worthwhile discussing some methodological aspects. First, the validity of using patent statistics in measuring innovative activity has been debated in the existing literature, and in the following a short overview of the main points is presented. Second, the causality between R&D investments, patents and industry activity needs to be addressed. Third, linking patent data to different industries requires the reflection of assumptions that emerge when using longer time-series.

3.2.1 Patents

Patents are regarded as one of the most useful indicators of innovative activity. Patents are by definition inventions and therefore represent technological change and development. In addition, patents are used in economics research due to the availability of the data as it is systematically collected, covers long time series, is electronically available, and is classified into technology specific categories. Patents

2 This paper uses patent data from the April 2008 version of the PATSTAT.

3 Although PATSTAT has data for years 2006 and 2007, these years are omitted due to the lags between filing and publication of the patent document, which causes the data to be insufficiently representative for these years.

are complementary to other innovation indicators such as R&D expenditures. These indicators measure mostly innovation input and are often macro-level data. Patents, on the other hand, allow innovation related questions to be approached with both macro- and micro-level data.

The usefulness of patent data in innovation studies is based on the information in the patent documents. Each patent publication produces a structured public document containing detailed information on the invention itself, the technological area to which it belongs, the inventors (e.g. their geographic location), and the organisation (i.e. assignee) to which the inventors assign the patent rights at the time of the publication of the patent document.

Patents have several advantages when measuring innovative output, but they also have some disadvantages that need to be addressed. In the following the advantages are weighted against the disadvantages commonly discussed in the literature (for further discussions see especially Griliches, 1990; Moed et al., 2004; and in Finland Nikulainen et al., 2005).

The *advantages* of patent data are mostly related to their availability and rich content. A patent is a publicly available document and can be accessed electronically either through the Internet or databases such as PATSTAT. Although most databases are either cumbersome or costly to use, the availability of worldwide patent data makes it compelling. The detailed information provided in the patent documents enables researchers to compare companies, nations, inventors etc. The patent information comprises dates, description/IPC class, assignee, inventors, designated states, citations, legal information etc. The data cover almost every field of technology, and detailed disaggregating is possible. Patent data allows the use of long time series that start as early as the 18th century.[4]

The *disadvantages* of patent data are related to its use as an indicator of innovative activity. The patentability of technologies varies (e.g. software and genetically modified substances are not as readily patentable in all countries), and hence this problem needs to be recognised in comparisons across different technology fields, industries or companies. Patenting is also a strategic option, depending on the specific strategies that companies choose in protecting their intellectual property. This is especially true for process inventions and inventions with short lifecycles which rely on other means of protection, such as secrecy or lead-time (Cohen et al., 2000). Further, inventions can build on several patents, only a part of the invention might be patented, or a single patent can build on several inventions. Hence, the technological meaning of a patent can be somewhat blurred. Therefore, we use patent family data that resolves part of this dilemma by pooling all the patent documents related to a single invention.

A patent family consists of all the patents and patent applications resulting from a single original patent application. Usually, a patent application for an invention is first filed in one country. Sometimes this patent application is then also filed in other countries. A single patent application might result in many patents throughout the world. Therefore, by approaching patents through patent families the analysis focuses more on actual individual inventions rather than on patent counts in different national or supranational patent offices. The members of the patent families are identified by the patent examiners based on technological similarity. While patent family level data allows for a more general picture of the inventive activity rather than patenting activity in different patent offices, and allows the use of long time-series, which are not available with office specific data (especially in the European Patent Office - EPO), this approach does not take into account the heterogeneity of the patent families. In our approach all patent families are treated as identical. Therefore, a single family with one patent in the Finnish patent office is seen as identical to a family with patents in USPTO (United States Patent and Trademark

[4] As a curiosity it might be mentioned that the first ever patent was granted in Finland in 1842 when sole rights to produce blowers of iron were given to L.G. Ståhle.

Office), EPO and JPO (Japan Patent Office). For the current paper this constitutes only a limited problem since the interest is on the general development and activity in patenting rather than on the estimation of the 'quality' of the patent families. The patent families related to Finland were identified by requiring that at least one of the inventors or assignees in any of the patent family related publications is Finnish. Thus the data consists of patent families that are either purely Finnish, that is, all the inventors and assignees are from Finland, or of patent families with a weaker link to Finland, for example only one Finnish inventor, with the other inventors and assignees being foreign.

When using patent data for analytical purposes, there is a problem regarding lags. There is a lag between application and grant dates (usually 3 years or more), as well as application and publication dates (usually 18 months). This aspect has been solved in the current paper by using the first available date associated to the patent family. In addition the identification of technology fields is tricky if technological knowledge of specific fields is not available. This partially relates to the connection between technology fields and industries – or discrepancies in the origins and use of the invention and the related technologies. Not all patents in a certain technology category relate to the same industry and *vice versa*. This aspect is discussed in more detail below, where the use of concordance tables in connecting technologies and industries is discussed below.

In conclusion, it could be said that patents provide an intermediate output indicator of innovative activity. Balancing between the advantages and disadvantages is to some degree a question of different trade-offs in research. Once careful consideration of the special features of patent data is taken into account, patents provide the only readily available (intermediate) output indicators of innovative activity.

3.2.2. Causality

The second methodological aspect is the causality between the variables used later in the statistical analysis. The causality becomes a significant factor when the discussion turns to the interaction between the different variables, and especially when lags are assessed. The aim in the analysis is to explain changes in the growth of industry volume through changes in the innovative output of the industry, which is approximated through patent statistics. Thus, one of the critical questions regarding causality is whether patents induce industry production growth or industry growth induces patent growth. One potential answer is that both options are true. This would imply that reverse causality exists. Reverse causality is true for R&D and patents (Arora et al., 2007). Arora et al. (2007) find that increases in R&D increase patenting which in turn increases R&D (i.e. R&D => Patents => R&D). This finding relates to the current paper as we aim to establish the connection between patents and industry growth. If reverse causality exists also in this context, it would mean that an increase in patenting induces industry growth, which again would induce patenting (i.e. Patents => Industry growth => Patents). This aspect will be addressed in more detail in Section 4 dealing with this question by the means of a statistical regression analysis.

3.2.3. Linking technologies and industries

The final methodological aspect is related to the use of patent data in an industry specific context. The question here is the need to link the technological classification of a patent to a specific industry. To solve this linking problem, there have been efforts to produce concordance tables indicating which technologies are most likely linked to any given industry. The concordance tables are a result of statistical analyses of the likelihood of a technology to belong to a specific industry. This is achieved by combining IPC classifications (International Patent Classification) of a patent to an industry classification (SIC or NACE) by identifying the owner company of the patent at the time of its publication. In this paper a concordance table developed by Schmoch et al. (2003) is used to link technologies (i.e. patents) to industries.

The use of concordance tables with long time-series patent data requires more discussion, because these tables have been developed with fairly recent data, thus potentially failing to take into account the technological development within industries. This raises questions related to knowledge-relatedness (Breschi et al., 2003) and the use of multiple technologies within companies and industries (Granstrand, 1998). While this might seem a major obstacle, there is evidence that companies tend to have similar technological portfolios over a long period or, in other words, they seem to be technologically path-dependent (Patel and Pavitt, 1997; Cantwell and Fai, 1999; Cantwell, 2000; Fai and von Tunzelmann, 2001). Thus, an assumption can be made that the use of concordance tables even with long time-series is a viable option.

4. DESCRIPTIVE ANALYSIS

Before going into more details about the patenting activity in Finland, it should be remembered that this paper focuses on analysing patents rather than on trying to tell the story of technological evolution in Finnish industries. The main reason for this setting is the nature of data at hand. To analyse the technological evolution in more detail more historical and especially qualitative data would be required. The setting for this paper is more focused on the quantifiable results that allow the creation of time-series and also facilitate statistical analyses, which might prove to be useful in assessing the use of patent statistics in predicting future industry growth. In the following descriptive analysis the focus is on the technological trends, both in different technologies and in specific industries.

To illustrate the overall picture of the innovative activity in Finland, the patent family counts are presented in Figure 5 and this trend is compared to the share of Finnish patents in the US highlighting the rapid increase in patenting.

Figure 5. The number of Finnish patent families 1842-2004 and the share of Finnish patents in US

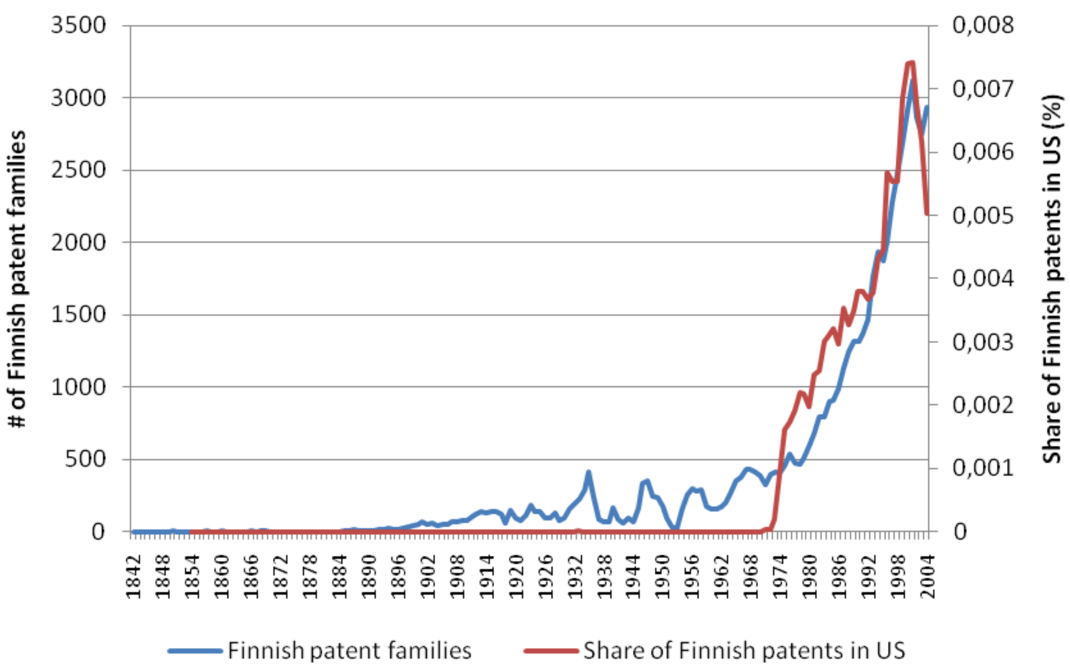
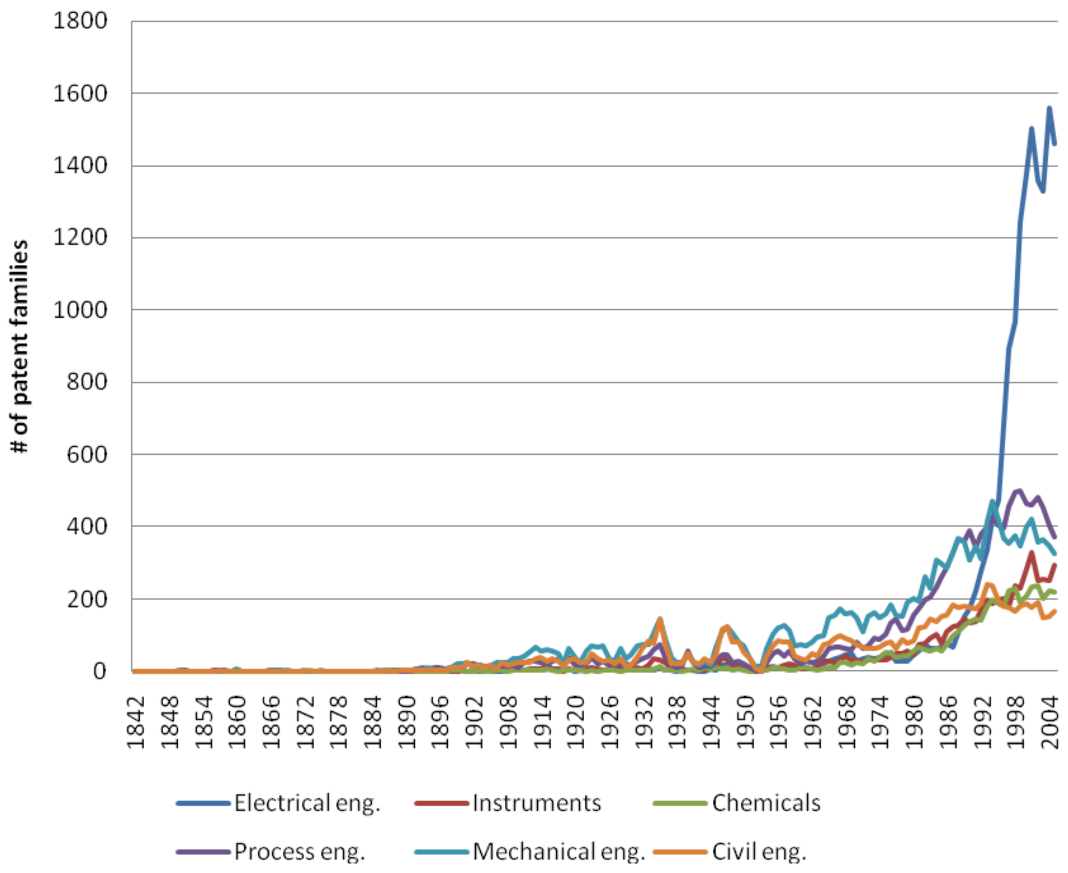


Figure 5 tells us that the earlier mentioned change from a resource-driven economy via an investment-driven phase to a knowledge-driven economy is evident also in the light of patent statistics. The number of Finnish patent families prior to the 1970s highlights the fairly low level of innovative activity, which corresponds with the fact that during this period most technologies were imported and not developed further. Later, in the investment-driven economy, the innovative activity starts to gain momentum, which shows that these imported technologies are developed further thereby creating a national competence especially in the metal and machinery industry as presented later. From the late 1980's onwards the technological development has picked up significantly driving Finland towards the current phase of a knowledge-driven economy. The share of Finnish patents in the US (having at least one Finnish inventor or assignee in a US patent) shows that the increase in Finnish patenting is not only due to the well-documented patent explosion in the last decades (Hall, 2004) and the increasing importance of patents, but rather from the earlier mentioned shift towards a knowledge-driven economy in Finland. In the following the aggregated patent family trend is first broken down to technology level and then discussed with respect to different industries.

4.1. Technology trends 1842-2008

The general trend in patenting was already illustrated above in Figure 5 and hence in the following the focus is on the trends in specific technology areas. In Figure 6 the technologies are presented in six technology areas (electrical engineering, instruments, chemicals, process engineering, mechanical engineering, and consumer goods and civil engineering).

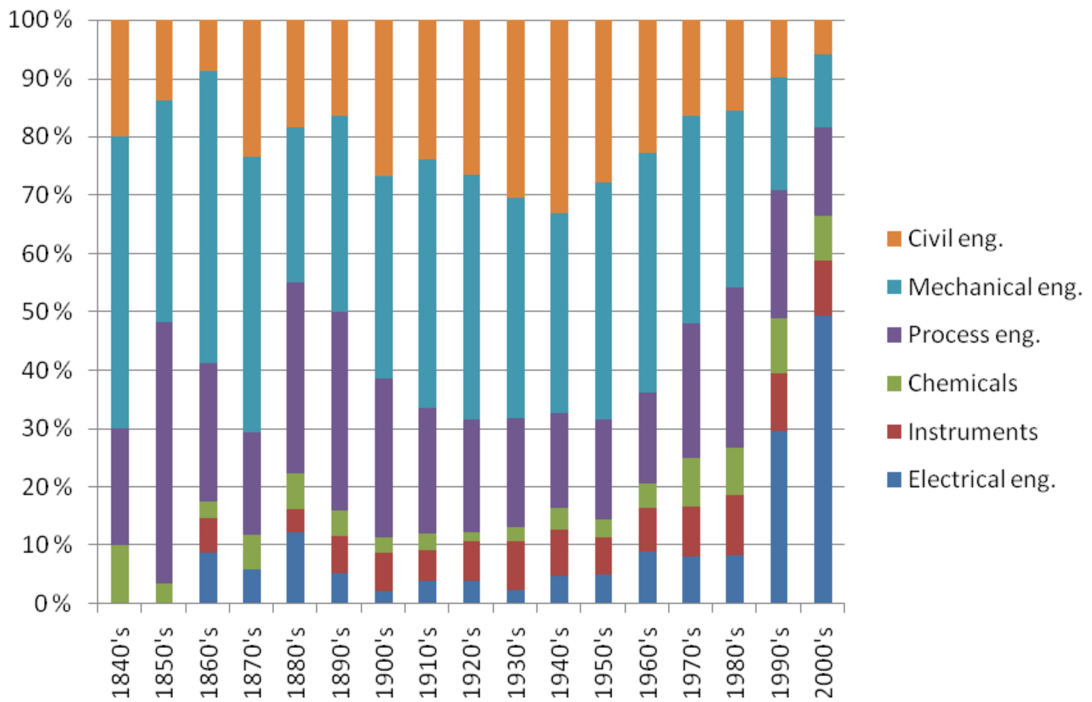
Figure 6. The number of Finnish patent families per technology 1842-2005



The patent family counts show that patenting activity has increased gradually until the 1960s, and since then all technologies have seen varying rates of positive growth. The most significant increase has been in electrical engineering, mostly due to the emergence of ICT technologies and the increasing importance of patents in this area (e.g. patent thicketing, licensing and cross-licensing). Interestingly, the other technologies seem to peak around 1995, and afterwards the growth has slowed down or even decreased. Taking into account the transformation of the Finnish economy from a resource-driven economy to a knowledge-driven economy, it is not very surprising to see that the patenting activity picks up in the beginning of the 20th century continuing fairly steadily until the 1960s when Finland became a more investment-driven economy. From the 1970s onwards the significance of the development of indigenous technologies, rather than the import of technologies and the improvement of imported technologies, starts to show in patent statistics.

While the general trends provide some insight into the changes in technological activities in Finland, a closer examination is worthwhile. In Figure 7 the shares of patents over decades highlight these changes more clearly.

Figure 7. Share of Finnish patent families per technology by decades (%)



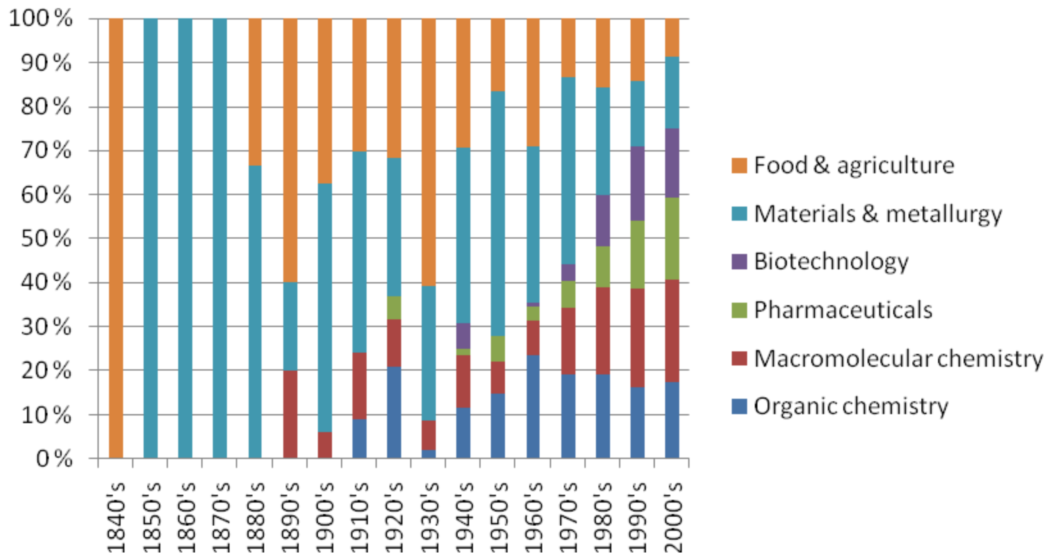
When looking at the shares of each technology decade by decade, the picture of technological change in Finland from Figure 6 becomes more evident. Naturally there has been a tremendous general global trend of ever increasing technological diversity through the emergence of new technologies. The most interesting findings from Figure 7 are related to these emerging technologies. While consumer goods and civil engineering, mechanical engineering and process engineering have been the major contributors to the technological landscape of Finland, instruments and chemicals have gained significance over time. As mentioned earlier, the share of electrical engineering has increased rapidly in the last decades, but interestingly there is activity in this area as early as the 1860's indicating some level of activity in this field, which is usually regarded as one of the most knowledge intensive technology areas.

While the share of the aggregated technologies provided some insight into the technological change in Finland, it is worthwhile extending the discussion to a more disaggregated level to highlight what kind of technologies really underlie these changes. In the following figures selected technology areas are broken down to more disaggregated technology fields.

Figure 8. Share of patent families in electrical engineering by decades (%)

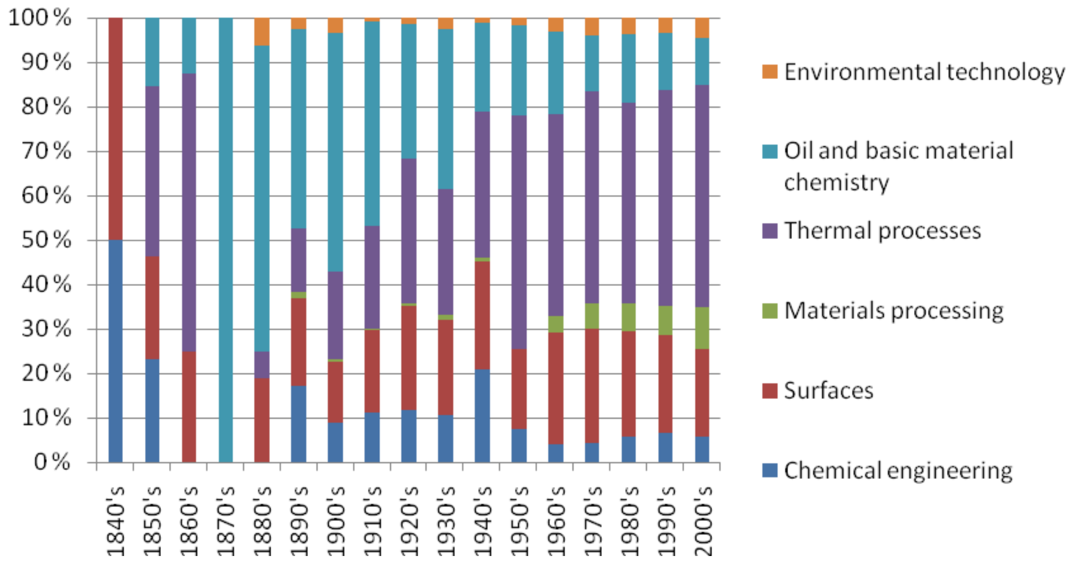
On a closer examination of the patenting activity in electrical engineering the reason behind the radical increase in the number of patents becomes more evident. The role of telecommunications (e.g. mobile phones) has experienced the most significant increase, whereas activity in audiovisual technology (e.g. televisions) has been reduced to marginal levels. Semiconductors appear from the 1980s onwards but are not a major factor when measured through patents. Interestingly, activity in electronics devices has became almost marginalised in recent decades having played a major role before the more knowledge-intensive period which started around the end of the 1980s. The emergence of telecommunications is mostly attributed to Nokia, although there are other actors as well. One of the most interesting finding is the early activity in telecommunications dating back as far as the 1880's. This relates to the early interest of wire-based telephone technologies (see Myllyntaus in Vuori and Ylä-Anttila, 1992).

Figure 9. Share of patent families in chemicals by decades (%)



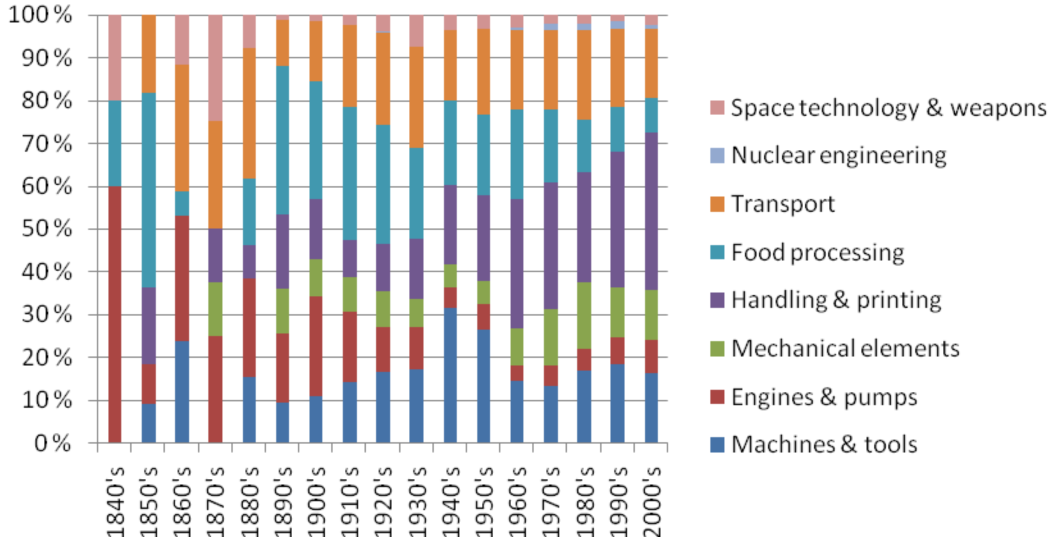
Reviewing the development in chemicals, an obvious change is related to the diversification of the technologies. While in the 19th century and in the beginning of the 20th century the food and agriculture related technologies as well as materials and metallurgy, were dominant, from the 1940s onwards the technological landscape changed. Pharmaceuticals, organic chemistry, and finally biotechnology started to have an impact on the technological landscape. It is important to note here that patenting activity in pharmaceuticals is boosted because method patents were used in Finland, which allowed the production of drugs patented by competitors abroad. This practice ended as late as in the 1990's. The emergence of modern biotechnology from the 1970s onwards highlights the increasing role of this science-based technology area.

Figure 10. Share of patent families in process engineering by decades (%)



Process engineering has been one of the most important technological areas in Finland. The activity in this field is related to the main traditional industries (i.e. pulp and paper, and machinery). The most interesting development is the increasing importance of thermal processes and the declining role of oil and basic material chemistry, which both indicate the change from production of standard goods towards higher value-added goods. The increasing activity in material processing is an interesting finding, because, for example, activities in nanotechnology are often related to this field (Palmberg and Nikulainen, 2006).

Figure 11. Share of patent families in mechanical engineering by decades (%)

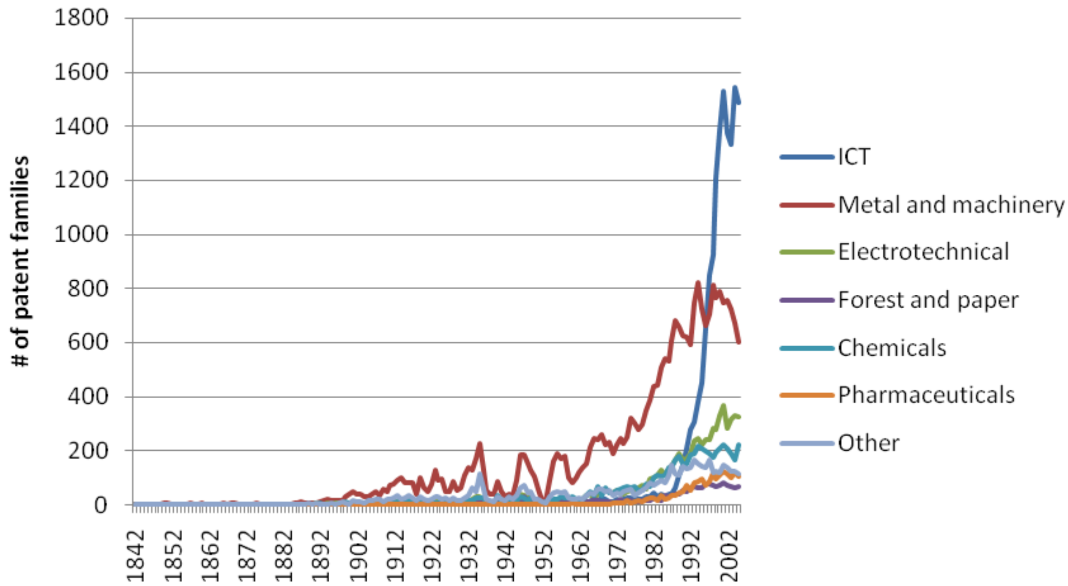


Similarly to process engineering, mechanical engineering has been, and still is, one of the most active technology areas in Finland. Again, as in the case of process engineering, this area is a technological cornerstone of the main traditional industries. Some interesting insights can be gained from Figure 11. Activity in handling and printing has increased its share, which is in line with the developments in some industries such as pulp and paper. Also the diminishing importance of food processing suggests that the industrial activity has strongly changed from primary production towards higher value-added goods and services as discussed in the beginning of this paper.

4.2. Industry technology trends 1842-2008

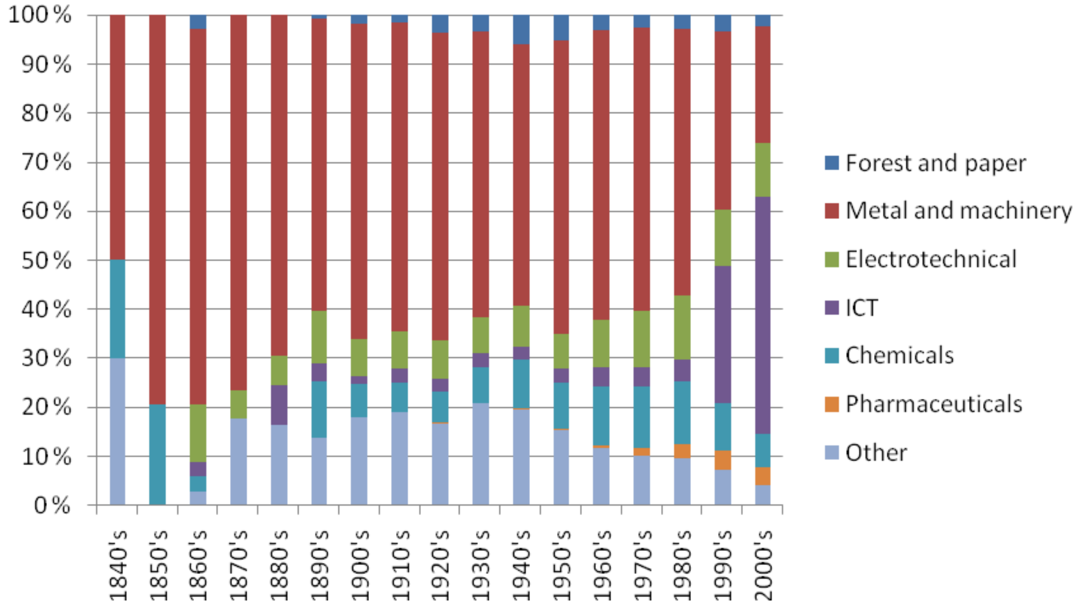
While the discussion above focused on the technological development through a description of different technological areas, it is still unclear how these technologies are connected to the technological development of industries. Therefore, we use a concordance table developed by Schmoch et al. (2003), which allows us to link specific patent classifications to specific industries, and thus creates a link between patenting activity and industries. In Figure 12 the technological development for the major industries in Finland is illustrated.

Figure 12. The number of Finnish patent families per industry 1842-2005



It is evident that some of the industries are following the technology trends illustrated earlier, while others combine different technologies or are active in a narrower technological area. ICT is a good example of an industry that relies heavily on the development in electrical engineering. The metal and machinery industry, on the other hand, combines technologies from different areas, most notably from process and mechanical engineering. Also the low level of activity in the forest and paper industry is somewhat surprising, but as the innovative activity in this industry is very supplier dominated (especially the machinery and chemicals industries), and in addition many innovations might not be patented as they might be process related, the results are more understandable. The large drop in the metal and machinery industry indicates that the innovative activities in this industry have reduced significantly in the last ten years suggesting that there might be challenges for future industrial renewal through innovations. By looking at the shares of patenting over time in Figure 13, the changes in industrial structure and in the underlying technological development can be illustrated.

Figure 13. Share of Finnish patent families per industry by decades (%)



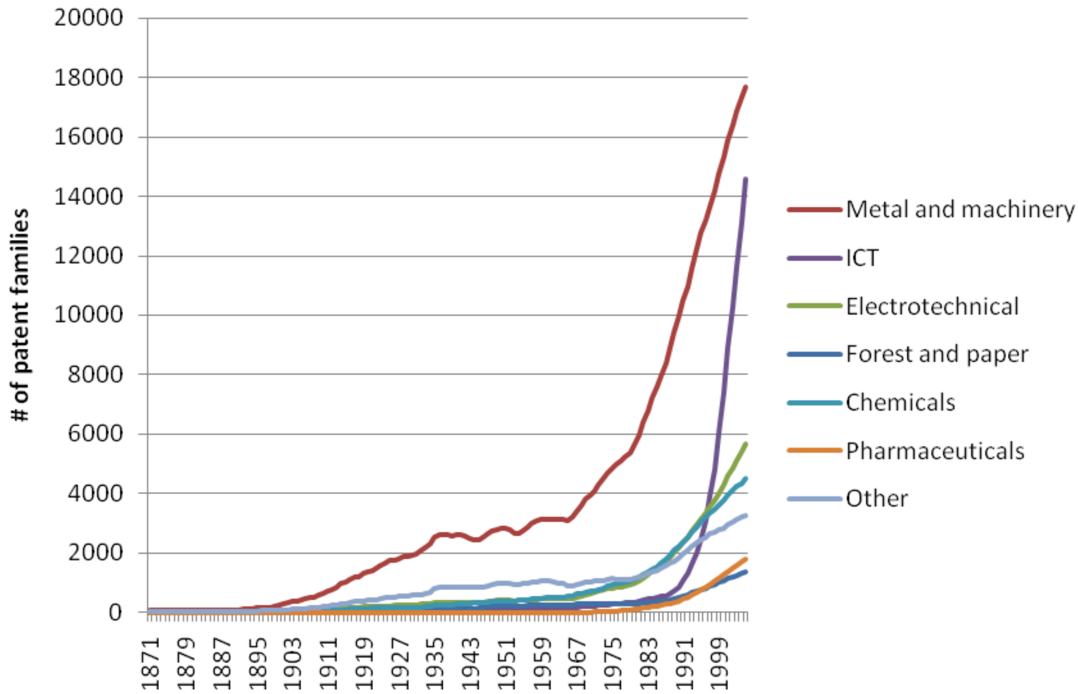
The changes in the shares of patent families per industry highlight the important role of the metal and machinery industry in Finland. This industry accounts for over 50% of all patenting activity until the 1980s when the ICT sector started to develop both in technological and industrial terms. Somewhat surprisingly there has been activity in electromechanical and ICT related technologies starting from the 1860s. This finding suggests the occurrence of early adoption of some of the technologies, but it seems that diffusion to industrial activity has been much slower. The main reason for this has been the general development of these technologies, but a partial reason can also be the dominant role of the traditional industries (forest and paper, and metal and machinery). To shed more light on what kind of companies are among the most innovate, Table 1 presents companies patenting most per decade.

Table 1. Most patenting companies – by decades (# of patent families)

2000	**1990**	**1980**	**1970**	**1960**	**1950**	**1940**	**1930**	**1920**
Nokia	Nokia	Valmet	Valmet	Valmet	Ahlström	Kymmene	Automaatti Teollisuus Oy	Maskin och Brogyggnadds Ab
Metso	Valmet	Ahlström	Wärtsilä	Ahlström	Valmet	Ahlström	Tikkakoski	Suomen Suojeluskuntajärjestö
Kone	Ahlström	Neste	Ahlström	Tampella	Kymmene	Wärtsilä	Sportartikel Ab	G A Serlachius Ab
Borealis	Metso	Tampella	Outokumpu	Wärtsilä	Rauma Repola	SOK	Maskin och Brogyggnadds Ab	Fazer Ab Oy
Outokumpu	Kone	Nokia	Rauma Repola	Nokia	Kone ja Terä	Heinolan Faneritehdas	Wärtsilä	Lahden Rautateollisuus Oy
VTT	VTT	Outokumpu	Tampella	Kone	Enso Gutzeit	Enso Gutzeit	Tampella	Finska Forcit Dynamit Ab
ABB	Neste	VTT	Nokia	Outokumpu	Heteka	Orion	Hankkija	Kymmene Lämmityslaite Oy
TeliaSonera	Borealis	Kone	Enso Gutzeit	Sateko	Tampella	Tikkakoski	Tilgmann Oy Ab	
Orion	Orion	Partek	Kemira	MKT Tehtaat		Outokumpu	Valio	
Wärtsilä	Instrumentarium	Rauma Repola	Kone	Fiskars				

An alternative approach to understanding the knowledge base in Finnish industries is to use patent stocks. In Figure 14 the patenting activity of the main Finnish industries is shown with the trend representing the cumulative stock of patent families over a 30 year period where the last year is depreciated when moving forward one year. This approach is sometimes used to highlight the importance of past technological developments, and 30 years is often seen as the length of a generation of technological knowledge that still might have an impact on current patenting activities (e.g. Andersen, 1998).[5]

Figure 14. Industry patent stocks 1871-2005



The most obvious advantage of using patent stocks is the ability to control for the annual fluctuations in patenting. Thus, the smoother lines provide a clearer picture of the overall development in each industry. The trends highlight the rapid growth in ICT, and in the metal and machinery industries. This supports the story of a change from a resource-driven economy via an invest-driven phase to a knowledge-driven economy.

In the following part of the paper the aim is to empirically examine the interaction between the above illustrated patent stock trends and the growth in industry production volumes in key sectors of the Finnish economy. The aim is to assess the use of patent statistics in predicting future industrial growth, which could provide useful insights into the dynamics between innovative and industrial activity.

[5] This approach omits the first 29 years of the data.

5. CONNECTION AND LAGS – STATISTICAL EVIDENCE

In the previous section the focus was on the technological development in Finland, which was discussed through the presentation of trends and shares. In the following regression analysis the aim is to establish whether there is a connection between technological change and industry development. In addition, we establish the lag-structure between the two components and thereby address the earlier mentioned causality aspects. The relationship between innovative and industry activities has been studied by many researchers usually through the analysis of R&D and productivity (especially TFP – Total Factor Productivity). Unfortunately these efforts have not produced conclusive evidence of the connection between economic growth and innovation. In some of the studies backward lags are introduced to highlight the temporal aspects (see e.g. Rouvinen, 2002), but still the connection between the two components remains somewhat unclear. The reason behind these inconclusive results might be that the variables used in the estimations are not optimal for empirical examination of this relationship. R&D investments measure the inputs to innovative activity and ignore outcomes, thus potentially indicating failed investments rather than materialised outcomes. Also the use of TFP has been criticised quite widely, because it remains somewhat unclear what is actually measured (see e.g. Lipsey et al., 2005).

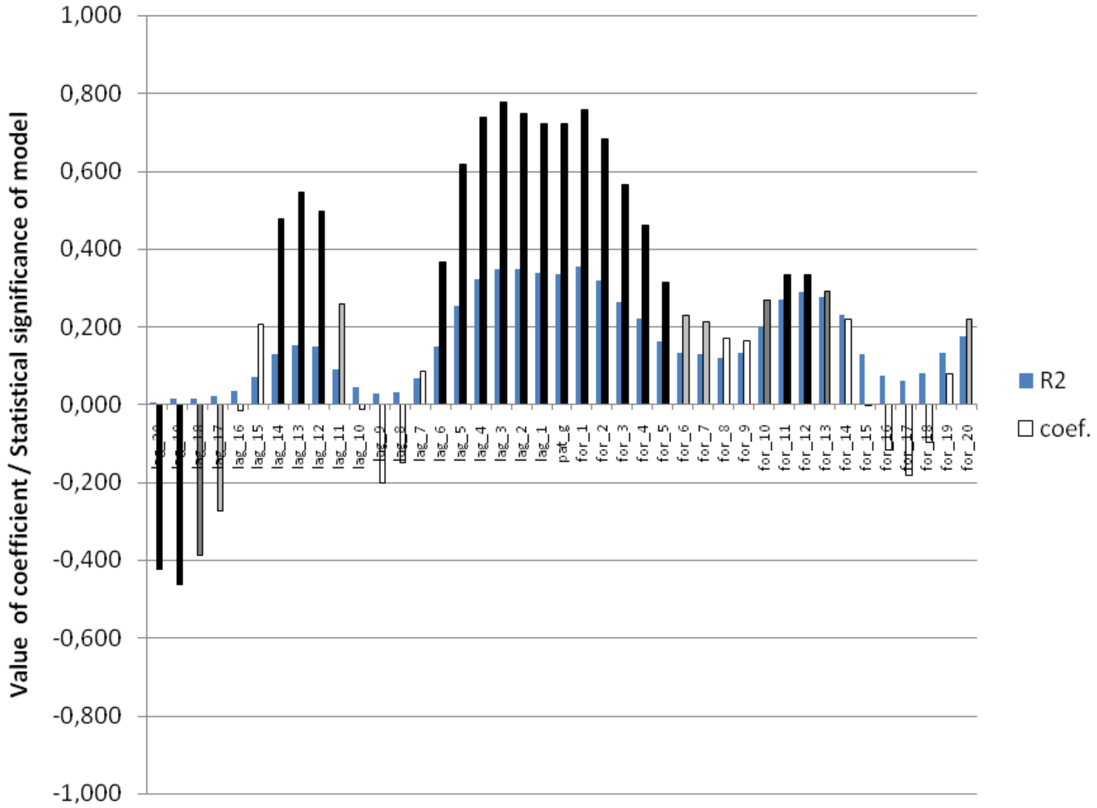
Instead of R&D and TFP, in this paper we used patents and industry production volume to analyse the connection between growth in industrial and innovative activity. For this purpose the following model is presented:

$$INDGROWTH_{it} = \alpha_{it} + PATGROWTH_{it}\,(or\ LAG_{iT}\ or\ FOR_{iT}) + YEAR_{it} + YEAR_{it}^2 + \varepsilon$$

, where *INDGROWTH* represents the 5-year moving average of growth in the industry volume in industry *i* (i.e. electronics, chemicals, paper and metal engineering) in year *t*; *PATGROWTH* is the annual growth in the 30-year patent stock in industry *i* in period *t* (*LAG* and *FOR* represent the backward and forward lags, where T indicates the size of the lag up to 20 years relative to the year in question); *YEAR* (year of observation) and *YEAR* (squared) are controls for time; and *e* is the error term. The data used in the analysis represents years 1951-2005, and thus provides cross-sectional panel data of 55 years for four industries.

The following analysis should be seen as an attempt to understand the connection between patent growth and industry volume growth. In future this aspect should be analysed in greater detail by developing the model further and by identifying the most suitable estimation methods. In this stage the approach is a simplified version employing separate OLS regressions with fixed effects (with respect to industries), and thus taking into account the cross-sectional nature of the panel data. In Figure 15 the results are shown. Each pair of columns represents a single regression, where the blue column indicates the R-squared and the other column the size effect of the co-efficient in question. The colour of the co-efficient column indicates statistical significance (black $p<0.01$, dark grey $p<0.05$, light grey $p<0.10$, and white – not significant).

Figure 15. Lag structure of industry volume growth and industry patent stock growth



The results show that there is a connection between the growth of the industry volume and the growth of the patent stock when industry differences are taken into account. The highest impact and significance is around the year of observation, which suggest reverse causality as discussed earlier in this paper. Interestingly, there are also weaker signals. Growth in patent stock about 13 years before the observation year provides a weak positive signal of future growth in industry volume. In addition, the industry growth is not only followed by an increase in patenting right after, but also about 12 years after the observation year. It should be noted that with longer lags the number of observations drops because backward and forward lags limit the use of first and last years of the sample.

6. DISCUSSION AND CONCLUSIONS

In this paper we aimed to illustrate the technological change in Finland using the general economic development as a framework. Finland has experienced a rapid change from a resource-driven economy to a knowledge-driven economy, which has created new industries and export goods that are often the result of knowledge intensive R&D. By using patents as a proxy for innovative activities the paper presented long time-series of technological trends both in different technological areas as well as in specific industries. In addition, the connection between industry growth and patent growth was addressed through a statistical regression analysis, which also allowed the use of backward and forward lags that emphasised the temporal dimensions and causality between the two components.

The results show that the technological change in Finland is highly related to the general economic development. The most important technologies in Finland have traditionally been process and mechanical engineering, which are related to the two cornerstones of Finnish manufacturing industries – forest and paper, and metal and machinery. The emergence of the current stage of economic activity (the knowledge-driven economy) is clearly a result of the increasing role of electrical engineering and the related industrial activity alongside the developments in the more traditional technological and industrial areas. The knowledge base is especially strong in the metals and machinery industry and in ICT, while in the other industries innovative activity seems to have lower starting levels and more incremental growth. These findings lead us to the more topical discussion of industrial renewal in traditional industries. The forest industry and especially the paper industry are currently undergoing a transition process, where the existing markets for current products are declining. Thus, the paper industry aims to introduce new and innovative products. This, however, might prove to be a large technological paradigm shift, which challenges the current innovation strategies in the industry. Furthermore, the paper industry has had a very supplier-dominated innovation environment, and, taking into account the low activity in patenting in paper industry, the transition process is likely to be difficult.

Another interesting finding is the strong knowledge base in the metal and machinery industry which somewhat surprisingly seems to have shown a downward trend for almost a decade. The change is not radical in volume, but the direction might indicate that the companies are less involved in innovation than before. As the metal and machinery industry has been and still is one of the cornerstones of Finnish manufacturing, the above-mentioned finding indicates less intense efforts to renew the industry when discussing the general development trends. This result might also suggest that the fairly strong growth in the industry is mostly due to the strong global demand for basic metals and the sales of existing goods rather than the introduction of new and innovative goods. This development has characteristics similar to the paper industry roughly a decade ago.

The most significant contributor to the change from the investment-driven economy to a knowledge-driven economy is the ICT industry. Patent indicators clearly show that the rapid technological development manifested itself quite seamlessly in industrial activity, in which Nokia naturally played a significant role. While the descriptive results indicated that innovative activities seem to make a difference in industrial activity at least for some industries, the connection between the two is still fuzzy. To address this aspect and the potential lags between innovation and industrial activity statistical regression analyses were used to shed more light on this issue.

The basic idea behind the regression analysis was to empirically examine the interaction between industry production volume growth and the growth of patent stocks while taking into account industry differences. It is evident that the effect is not only simultaneous, but there is also most likely a temporal lag, both backward and forward, between the two components. The regression results confirmed that there is indeed a connection between the two, with the positive connection between industry growth and patent growth being most evident around the year of observation. Interestingly there were also weaker signals that indicate that industry growth could be predicted based on patent activity with a lag of 13 years. This finding might be useful in assessing which technologies have the potential to increase industrial activity. Another finding is the confirmation of reverse causality. Patent growth induces industrial growth which, in turn, induces patent growth. This might provide insights into the existence of positive innovative cycles and their impact on industries.

The paper provides interesting insights into the technological change in Finland and its role in industry growth. Specifically, the results highlight the understanding of temporal dimensions of the connection between the two components and their potential use in predicting potential technological trajectories that might induce industrial activity. While this research provided interesting results, there are research directions that would significantly complement these findings. One of the aspects that was not discussed in this paper is the scope and scale of innovative activities on the company level (Cantwell and Fai, 1999; Cantwell, 2000). This approach would provide micro-level information, contrary to the macro-level evidence presented in the current paper, of the scale of innovative activities in individual companies, and how the scope of the companies technological profiles have changed over time. This would provide valuable information on the technological dynamics in different companies and industries. This approach could also clarify the role of large multinational companies in the Finnish innovation system.

The current paper should be seen as a step towards understanding the interaction between industry and innovative activity. By developing the estimation methods and conducting sensitivity analysis with different industries and with different time periods would strengthen the arguments presented here. Furthermore, to widen the generality of the results international comparisons should be undertaken, which would allow the identification of similar patterns in other countries and possibly highlight the national characteristics of the transition process in Finland from a resource-driven economy to a knowledge-driven economy.

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LÖNNROTINKATU 4 B, FIN-00120 HELSINKI

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