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ABSTRACT

From Natural Resources to High-tech Production:
The Evolution of Industrial Competitiveness in Sweden and Finland*

This paper describes and analyses the evolution of industrial competitiveness in Sweden and Finland in a long-term perspective. One part of the paper looks at the foundations for industrial take-off in Sweden, with some focus on the development of institutions for the creation and dissemination of the skills and knowledge needed in the emerging industrial sector. Another part narrows the focus and examines the emergence of Finnish Nokia and Swedish Ericsson as market leaders in the high-tech mobile telecommunications industry. The emphasis here is on the transformation of Nokia from a producer of simple raw material based goods to a knowledge-based high-tech company.

A conclusion from this paper is that an industry's success is a mix of systematic knowledge creation and random technological innovation. The experiences from Sweden and Finland suggest in particular that public policy should provide an appropriate institutional framework to facilitate the sustainable use of land, raw materials, and other resources and promote learning and internationalization.

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1. INTRODUCTION

Sweden and Finland are among the world's richest and most highly developed economies today, but it is often forgotten that the Nordic region was still one of Europe's poorest and most backward corners around the middle of the 19th century. The remarkable transformation that commenced around 1850 in Sweden and some decades later in Finland has gradually changed both countries from underdeveloped agricultural economies to advanced industrial welfare states. This process is interesting not only from an historical perspective, but also from the point of view of today's developing economies.

One of the distinguishing features of the Nordic development history is that growth was fuelled by the expansion of industries based on domestic raw materials, such as timber and iron ore. From a position as suppliers of simple intermediate products to more advanced economies in Western Europe, Sweden and Finland were able to upgrade the technological level of their raw material based industries, and establish a foundation for a more diversified economic structure. Over time, both countries managed to successfully diversify into related activities, such as machinery, engineering products, transport equipment, and various types of services. Many of today's developing economies have abundant supplies of natural resources, but few countries seem to base their long term development strategies on resource intensive sectors. The reason is arguably the risk that they may never be able to move from production and exports of low value added commodities to more advanced industries. However, the Swedish and Finnish experiences suggest that development strategies based on raw materials may form a solid base for sustainable development, and demonstrate some of the requirements for diversification and growth of more advanced industries.[1]

Another notable observation regarding the Nordic economies is that industries based on domestic raw materials still account for a significant share of manufacturing activity, although the export, production, and employment shares of more knowledge intensive manufacturing and service sectors have increased rapidly during the past decades. The forest and metal industries together employ almost one-fifth of the industrial labor force in Sweden and supply about a quarter of total Swedish exports – in Finland, the corresponding shares are even higher. The continuing prominence of these sectors implies that raw material based production is not only a temporary stage in economic development, but can instead be a sustainable element of an advanced industrial structure. This kind of long-run success requires public policies and company strategies that preserve the raw material resources and create the skills and competence that are needed to remain competitive in the face of increasing labor costs and changing technologies.

A third point to note is the rapid change in industrial structure that has taken place in both Sweden and Finland during the past decade. Since the early 1990s, Sweden and

[1]For a more comprehensive discussion about the relevance of the Scandinavian development model for today's developing countries, see Blomström and Meller (1991). This volume also points to the importance of political and demographic factors in long run growth.

Finland have taken leading roles in the development and application of information and communications technologies, and enjoyed remarkable success in knowledge based sectors. For instance, the Swedish firm Ericsson and the Finnish Nokia are world leaders in the telecom industry, and have accounted for a major share of the very significant export increases recorded in the two countries during the past decade. Table 1 shows how the world market shares of Sweden, Finland, and some other advanced countries in four broad industry groups have changed from 1980 to 1996. The industry groups are distinguished by their level of technological sophistication, ranging from high tech industries like telecommunications and pharmaceuticals to low tech sectors like wood and paper products. The most striking feature of the table is the rapid growth of the Swedish and Finnish world market shares in the high tech sectors. It is also notable that the fastest changes have occurred during the 1990s. As late as 1990, computer and telecom products accounted for less than 7 percent of Swedish and Finnish exports. By 2000, this share had increased to nearly 20 percent in Sweden, and 30 percent in Finland. This development is very encouraging for small countries that are arguably in a relatively weak position in R&D intensive sectors were economies of scale are important, but raises many questions regarding the explanations for the Swedish and Finnish success in this field.

Table 1 Changes in world market shares in broad industrial groups, 1985, 1990, and 1996. Index 1980=100.

	Technology level											
	High			Medium high			Medium low			Low		
	1985	**1990**	**1996**	**1980**	**1990**	**1996**	**1985**	**1990**	**1996**	**1985**	**1990**	**1996**
Sweden	94	91	130	90	86	90	120	129	111	98	89	80
Finland	100	167	321	94	82	93	87	103	121	86	79	69
UK	80	87	91	135	115	113	115	79	86	85	88	91
Germany	86	88	76	111	140	138	127	113	139	104	115	97
Japan	143	122	107	93	107	91	95	112	95	107	66	53
USA	98	90	86	89	103	92	99	128	106	90	92	102

Classification of industries
High technology: pharmaceuticals, computers, telecommunications equipment, aeroplanes.
Medium high technology: chemicals, machinery, electronics, transport equipment, instruments.
Medium low technology: petroleum, plastics, stoneware, steel, metal products, shipbuilding.
Low technology: food products, clothing and textiles, wood products, paper and pulp, printing.
Source: M. Hultin (2000), "Internationell handel, en möjlig tillväxtmotor!" in Svenskt näringsliv och näringspolitik 2000, Nutek, Stockholm. based on the OECD–STAN Database 1998.

This paper aims to describe and analyze the evolution of industrial competitiveness in Sweden and Finland in a long-term perspective, with some focus on lessons for growth and development strategies in today's developing countries. Section 2 looks at the foundations for industrial take-off in Sweden. The focus is on Sweden, for good reasons. Swedish economic development has progressed in a remarkably steady fashion during the past 100 or 150 years – the average annual GDP growth rate has been around 2 percent, with few booms and depression. The main explanations are that Sweden managed to stay out of the two world wars, and that political development has been very stable, with few (if any) dramatic changes in economic policies. Finnish development, by contrast, has been rocked not only by the Second World War, but also by a civil war,

a long period as a Grand Duchy under Russian rule, and many decades under the shadow of the Soviet Union. This notwithstanding, most of the factors underlying Swedish industrialization are found in Finland as well.

Section 3 discusses the factors underlying the success of the telecommunications industry in Sweden and Finland, which has taken over as the strategically most important sector, at least in a short and medium run perspective. Here the focus is on Finland, since Nokia's breakthrough has been more surprising than Ericsson's (which emerged as a world leader in the telephone industry already at the end of the 19th century). The tentative conclusion from our analysis is that the industry's success is a mix of systematic knowledge creation and random technological innovation. Although it is impossible to plan major technological breakthroughs, such as the digital telephone exchanges underlying the GSM cellular phone systems, we argue that it is possible to create an environment where firms or entire industries are well positioned to adjust to changing conditions and to benefit from innovations and market opportunities.

There is also a concluding section.

2. CREATING A BASE FOR INDUSTRIALIZATION: THE SWEDISH EXAMPLE.

During the 100 years from 1870 to 1970, Sweden developed from one of the poorest countries in Europe to one of the richest and most advanced economies of the world. This development was fuelled by the growth of several raw material based industries: sawn wood, pulp and paper, iron ore, steel, and grains were the most important ones. In this part of the paper, we summarize some of the factors contributing to the Swedish industrial breakthrough. The purpose is to highlight two central observations. Firstly, much of Swedish growth and development has been determined by factors that have little to do with domestic policies, such as foreign demand for Swedish products. Secondly, when domestic policies or decisions have been important, they have typically influenced institutions, education and learning. These observations are relevant also for the present debate on development strategies, since they suggest what type of policy interventions are possible and desirable.

Section 2.1 points to some important prerequisites for the Swedish industrialization process, while Section 2.2 goes on to describe the industrial breakthrough, with some emphasis on the role of technology transfer and the creation of domestic competence.

2.1 The Prerequisites for Industrialization

Most studies of Swedish economic history suggest that industrialization commenced around the middle of the 19th century, and that the real take-off occurred some decades later, during the 1870s and 1880s. However, the Swedish economy had begun to change already from the beginning of the 19th century, and the transformation laid a necessary foundation for the subsequent industrialization process. This foundation was, to some extent, created through conscious policies in agriculture and education, but exogenous technical changes also played an important role.

Agriculture

The most significant changes took place in the agricultural sector. Up to the end of the 18th century, Swedish agriculture had relied on archaic production techniques, and harvests were barely sufficient to feed the population. Famines were not uncommon: the last wide-spread famines occurred in the early 19th century. Three main changes contributed to a transformation of agriculture that began around 1800, and continued through the 19th century.

Firstly, the structure of land ownership was reformed. Traditionally, the land holdings of rural families had been divided into several separate strips of land, dispersed around the village. The purpose was to make sure that farmland of different quality was distributed fairly among all families belonging to the village. However, the fragmented ownership pattern also contributed to inefficiency and slow diffusion of innovations, since all production decisions - including adoption of new technologies - had to be coordinated among the village members. To overcome these obstacles, land reforms were undertaken in most parts of the country during the first decades of the 19th century. The traditional ownership pattern was broken up, and land was redistributed so that each farm got one larger plot instead of the many separate pieces (see further

Carlsson, 1980). In some parts of the country (especially in the more fertile southern regions), this also meant that the villages were broken up: the peasant families moved their houses from the village to the center of their own plot of farmland.

Secondly, new production techniques were adopted, and agricultural productivity increased. This was partly a result of the land reforms – diffusion of new techniques became faster when it was not necessary to convince the village majority about adoption of new practices – but it was also related to technical progress in the machinery industry. The most important innovations during the early part of the century were better ploughs, and after the 1850s machinery for sowing, harvesting, and threshing also became widely used. Furthermore, increasing use of fertilizers made more intensive cultivation possible.

Thirdly, potato became the new staple crop. It had been introduced to Sweden several centuries earlier, but its breakthrough did not come until the end of the 18th century. Potato was well suited to Swedish conditions, and it yielded larger harvests than the traditional staple foods, beets and turnips.

One result of the changes in the agricultural sector was a marked improvement in food supplies. Together with improvements in medicine (and a long period of peace beginning in 1809), this led to rapid population growth. During the first 60 years of the 19th century, the Swedish population increased from 2.3 million to about 4 million. The area of farmland grew from 1.5 million hectares in 1800 to 2.6 million hectares in 1850 and 3.6 million hectares in 1900 (Larsson, 1991, p. 28). Agricultural productivity grew continuously, and output sufficed to feed both the farmers and a growing urban population. In fact, Sweden became a significant exporter of cereals in the 1850s. This is remarkable, since the country had been a steady net importer of grains until the 1830s.

It is hardly possible to over-emphasize the importance of the improvements in agricultural productivity for Swedish industrialization. The higher productivity facilitated the transfer of labor to urban occupations, and made possible exports that generated capital for investments in forestry and manufacturing. The increasing rural incomes also translated into demand for the goods produced in the emerging manufacturing industries.

Education and Human Capital

Another important development that had commenced before the advent of industrialization was an improvement in the level of education and human capital. Like the institutional changes in agriculture, this was also a result of conscious policies. Both formal and informal types of education and training were supported by the state and some private institutions.

At the summit of the formal education system were the old universities in Uppsala and Lund, established already in the 15th and 17th centuries. These expanded throughout the 19th century, with heavier emphasis on the natural sciences than earlier (when law and theology had been the dominant subjects). Institutions for advanced technical education were founded during first half of the 19th century: both the Technological Institute in Stockholm and the Chalmers Technical School in Gothenburg, which later became the country's first technical universities, were established in 1820s. The universities and the technical schools played a central role for the creation of new technology. Many of the successful Swedish innovations that emerged towards the end of the 19th century were made by people educated in these institutions, as we will discuss in closer detail later.

The introduction of a mandatory school system in 1842 was also crucial for the creation of a skilled human capital base and for the dissemination of technologies. The official ambition was to guarantee basic skills in reading, writing, and arithmethics to all citizens, and literacy rates reached nearly 100 percent within one generation. This was essential for the ability of individuals and firms to learn and adopt new technologies: much elementary learning and technology transfer was based on written instructions, like blue-prints and handbooks.

Parallel to the development of formal education, there also appeared other institutions that were involved in development of technology and industry. The Royal Swedish Academy of Science dated back to 1739, and the Swedish Ironmasters' Association was established in 1747. The Ironmasters' Association, which was partly state-financed, was particularly important for the transfer of foreign technology to Sweden. The Association started the publication of the mining science journal *Annalerna* in 1817, and financed a very large number of foreign study trips made by Swedish engineers and scientists, requiring detailed written reports that were made available to the rest of Swedish industry. New engineering workshops, like Motala Verkstad, established for the construction of lock-gates and iron bridges for the Göta canal network in the early 19th century, were also indispensable as training centers. In addition, it is necessary to note the importance of labor migration. Swedish engineers were often trained and educated in Great Britain and Germany, and important contributions were made by several British engineers that immigrated to Sweden (Schön, 1982). Ahlström (1992) argues that Sweden possessed the fundamentals of a modern engineering industry already by about 1850, as a result of this development of technical skills and competence.

Protoindustrialization

The industrialization process was also facilitated by the development of primitive manufacturing activities - a kind of protoindustrialization - which had begun several centuries earlier. Unlike the changes in agriculture and education, these activities were not part of any explicit policy to strengthen productivity or technical progress, but they provided valuable skills and expertise for the industrial era.

One type of industrial operation that existed before the 19th century had grown from the Swedish army's procurement of supplies and equipment. Cloth, uniforms, weapons, utensils, tobacco, and alcohol were produced by so called "manufaktur" companies, and these were relatively large, although their production methods were primarily based on handicrafts. Yet, they provided some elements of industrial culture, and the towns where the "manufaktur" firms were located had an advantage over other locations after the advent of the industrial revolution.

Due to the highly seasonal nature of Nordic agriculture, the rural households had traditionally produced significant amounts of handicrafts during the winter months: leather goods, textiles, shoes, and simple tools were made by most families. After 1800, this production increased and became more specialized, both because of population growth and increases in agricultural productivity, and because demand was growing due to higher incomes. In some parts of the country, merchants purchased a large share of the output, and they sometimes commissioned the production of entire villages. The main significance of this type of activity may have been the development of commercial skills. As modern technologies for production of textiles became available after the

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middle of the 19th century, the Swedish textile factories were often established by merchants who had been involved in the trade with handicrafts.

A related development was apparent in mining and forestry. Swedish producers had strong positions in the European markets for copper, iron, and tar already from the 17th century, and it has been argued that one of the most important skills learned during the early years was international marketing (Hallvarsson, 1980, p. 13). Merchants and traders were involved in the establishment of many of the ironworks and sawmills that emerged because of good export opportunities during the 19th century. Hence, some important elements of industrial culture were in place already before industry was.

2.2 The Industrial Breakthrough

The industrial breakthrough was largely based on the progress in agriculture, education and skills, and handicrafts discussed above, but it was triggered by several other events that occurred more or less simultaneously around 1850. These were related to increasing foreign demand for Swedish products, and to technical innovations, the continuing development of skills and competence in Sweden's emerging industrial sector, and some important institutional changes.

Exports.

The most important reason for the inception of Swedish industrialization in the 1850s was a boom in foreign demand for Swedish products. Export demand continued to be a major determinant of industrial development throughout the century, although the domestic market took the lead towards the 1890s. The early stages of the Swedish industry's growth was fuelled by exports of simple products like sawn wood (and cereals), whereas more advanced commodities like pulp and paper and iron ore became the main exports later on.

Exports of cereals were of tremendous importance for the industrialization process, although their origin was in the agricultural sector rather than in manufacturing, and although the era of cereal exports lasted only from the 1850s to the 1880s. One reason was that the expansion of agriculture during these three decades provided employment for the increasing population at a time when industry was not sufficiently developed to absorb enough employment. Another reason was that exports brought in large amounts of capital, which were used to finance important parts of the early industrial expansion.

Sweden had been a net importer of cereals until the 1830s, as noted earlier, and exports were still limited during the late 1840s, reaching some 40,000 barrels annually. At the peak, 30 years later, exports had grown to 4 million barrels per year (Carlsson, 1980, p. 212). The reasons for the cereal boom were largely to be found outside of Sweden. Demand was high, especially from England, where the industrialization process had taken off, and domestic cereal production was not sufficient to feed the growing urban population. Bad harvest in England and elsewhere on the European continent during the early 1850s increased demand further. At the same time, Swedish harvests were unusually plentiful. Moreover, the leading European cereal exporter, Russia, was hit by the Crimean War in 1853-56, and Russian exports ceased almost completely.

The successful Swedish response to these new export opportunities was a combination of the flexibility of the agricultural sector (that had been created by the institutional changes in the structure of land ownership) and the appearance of various

technical innovations that increased productivity, e.g. machinery for sowing, harvesting, and threshing. Sweden managed to hold on to large shares of the English cereal imports until the 1880s, but the trade disappeared as suddenly as it had emerged after that. The reasons were that Russian exports resumed at large scale, and the United States emerged as the new leader when the Great Plains had been taken into production.

From the middle of the 19th century, there was also an increase in the demand for forest products - mainly pit props and sawn wood - that was fed by the English urbanization. Swedish exports of sawn wood products had been insignificant before the 1840s, for several reasons. Norway was a stronger exporter, both because of shorter transport costs and because the technical level of Norwegian sawmills was higher. In addition, the English *Navigation Acts* gave preferential treatment to Canadian producers (Carlsson, 1980, p. 218). However, the situation changed very rapidly in the early 1850s. The English import protection was abolished, and the Norwegian forest resources were over-exploited, which gave ample opportunities for Swedish wood exporters to step in. Other factors that facilitated the export success were of an institutional or technical nature. Most importantly, the Swedish state had restructured its forest holdings some years earlier. Large amounts of forest land had been distributed to private owners, especially in Southern Sweden, and the structure of forest ownership had been registered. This meant that property rights were well defined, and the private owners were in a position to respond rapidly to the increasing export demand. There were also some technical improvements, as steam-powered saws were introduced, and the sawmills became more efficiently organized, after Norwegian models. In fact, several Norwegian firms moved to Sweden, because of the dwindling forest supplies in Norway.

As a consequence, exports of sawn wood increased from less than 200,000 m^3 in the 1830s to 4,800,000 m^3 at the end of the century. In the 1870s, wood products had grown to make up 43 percent of Swedish exports (Hallvarsson, 1980, p. 14).

Later on during the 19th century, there were new export booms, for pulp and paper and iron ore. Exports of pulp and paper began growing towards the end of the 19th century, and Sweden had become the world's largest pulp exporter by 1913. However, this expansion differed from the sawn wood boom in several ways. Sawmilling had been an easy start, since the capital requirements were low and the technology was simple. Pulp and paper production was significantly more capital intensive and technology intensive, and posed much stricter requirements on domestic institutions and technological competence than sawmilling had done. Domestic policies were also much more important for the success of the industry. Thanks to the development of a relatively efficient banking system, profits from sawmills could be channeled to finance the expansion of pulp and paper mills. The development of domestic technological capability had also proceeded far enough to allow production and exports of more advanced goods. In fact, Swedish inventors had taken the lead in the development of pulp technologies, and the world's first chemical pulp factory was established in Bergvik, on the coast of Norrland, in 1872.

The mining industry that started expanding during the last decades of the century was also heavily dependent on modern technology. Table 2 illustrates the changes in the structure of Swedish exports between 1881-85 and 1911-13. The relative importance of sawn wood and cereals fell, whereas more advanced products, like pulp and paper, engineering products, and iron ore became more important.

Table 2 The structure of Swedish exports 1881-85 and 1911-1913.

	1881-85 (percent)	1911-13 (percent)
Sawn wood	40	26
Iron and steel	16	9
Cereals	12	1
Butter	6	6
Pulp and paper	5	18
Engineering products	3	11
Iron ore	-	8
Other	18	21
Total	100	100

Source: Larsson and Olsson (1992), Table 3.

Domestic Demand.

The driving force behind the early stages of industrial development, during the 1850s and 1860s, was undoubtedly export demand. However, the domestic market became gradually more important, partly as a result of explicit policy intervention. One example was the development of the domestic infrastructure. The heavy investments in railroads (especially during the 1870s) and the introduction of electric energy (from the 1880s) made it possible to specialize production and transport raw materials and finished goods across the country. The earliest industrial developments, in e.g. sawmills, had relied on waterways, but now a more general industrialization, based on the domestic markets, was possible. The demand for metal and wood generated by the construction of infrastructure facilities, mainly railroads, also stimulated domestic demand.

Another reason for the heavier emphasis on the home market was more directly related to policy. The export booms during the early stages of the industrialization process took place at a time when economic liberalism and free trade ideologies reached a first peak. This meant not only that Sweden could freely sell primary products to the rest of Europe, but also that Sweden imported much of advanced consumer and investment goods from the industrially more developed countries in Europe. These policies changed from the late 1880s, when a wave of protectionism swept over Europe. Both agricultural and industrial imports were restricted, and the average tariff level in Sweden before the First World War reached about 15 percent of value added. A further sign of the changing policy climate was the introduction of policies to limit foreign ownership of Swedish resources. Earlier, foreign participation and investment had been welcomed. This meant that domestic markets became more important, since similar developments occurred in the rest of Europe as well.

One can only speculate about the significance of the timing of policy regimes. It appears that Sweden was fortunate, in that the inward-looking policies were not introduced until there was a firm base for domestic development. Agriculture had expanded and the increased productivity created incomes and demand for various types of consumer goods. Technological skills had been developed, which facilitated the creation of a variety of import substituting industries. The export success had brought in foreign capital, and a foundation for a more comprehensive industrialization was in

place. These elements have not been in place in most of the developing countries where inward-looking policies have failed during the 20th century.

Technical Innovations

In addition to the exogenous changes in foreign demand for Swedish products, there were exogenous changes in technology that had a heavy influence on the direction of Swedish industrialization.

In the metal industries, Sweden had held a strong position in the international market for several centuries. The main export product until the middle of the 19th century was bar iron. The production of iron was strictly controlled by the state, in order to avoid deforestation and degradation of forest resources: the industry used massive amount of timber, in the form of charcoal. It has been estimated that mining industry's use of wood was 4-5 times larger than wood exports as late as 1854. Hence, exports of iron ore and pig iron (which were low value added products) were restricted.

The strict rules were liberalized in 1850s, when technological innovations - the Bessemer and Martin processes - made it possible to use coal and coke instead. However, the Swedish production and exports of iron and iron ore stagnated during the decades after 1850, because the comparative advantage of the Swedish iron industry had been the abundant supply of charcoal. Instead, coke and coal based steel production in continental Europe increased rapidly. It was not until the so-called Thomas process was introduced that the industry started recovering. It was known since centuries that there were rich iron ore deposits in northern Sweden (Lappland). These had not been exploited earlier because of their high content of phosphor, which made the steel weaker. Now it became economically viable to develop the industry, and new ironworks were established. Production of steel for domestic use increased rapidly, but exports of steel remained low. Instead, iron ore was exported directly to the main iron and steel plants in Germany and Great Britain.

The development of mechanical and engineering industries, which started during the latter part of the 19th century, was also driven by technological innovations, but these were more directly connected to domestic capabilities and skills. Especially the 1880s proved to be a golden decade for Swedish industry, when several path-breaking innovations were presented, and when industrialization really took off: the number of industrial workers increased by 66 percent between 1880 and 1889 (Hallvarsson 1980:9).[2]

Examples of long-lived Swedish firms that were established during the late 19th century or the first years after the turn of the century are Ericsson, Alfa Laval, ASEA (today ABB), AGA, Nobel, and SKF. The exceptional performance of these firms has been based on the ability of Swedish industry to create, adapt, and disseminate new technologies. The development of institutions for science, technology and education has made up the foundation for this kind of success.

Science, Technology, and Education

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[2]Yet, agriculture was still the dominant activity. It was not until about 1900 that the GDP share of manufacturing equalled and eventually surpassed that of agriculture, and agricultural employment remained larger than manufacturing employment until the 1930s (Jörberg, 1984, pp. 9-10).

The first technical universities of Sweden date back to the early parts of the century. The Technological Institute in Stockholm was founded in 1826, and it became the Royal Institute of Technology in 1877. In Gothenburg, the Chalmers Technical School was established in 1829, and it provided scientific and technical education at a university level already from its inception, although it was not formally named a Technical University until 1937 (Ahlström 1992:4). Concurrent with the development of specialized institutions for technical education, there was also an expansion of the natural sciences at the universities in Uppsala and Lund, and it has been argued that the great increase in the number of professorial chairs between 1870 and 1914 was of "immense importance" for the industrial breakthrough (Ahlström, 1993:38).

Technical colleges were established in several Swedish cities - Malmö, Borås, Örebro, and Norrköping - during the 1850s. From the middle of the century and onwards, numerous vocational training schools were also set up in various parts of the country, to number about 35 at the end of the 19th century and 66 in 1908-1909 (Ahlström, 1992, p. 7). The guild system was abolished in 1846, and these schools quickly began to replace apprenticeships as the main form of vocational education. Most of the vocational schools depended on private initiatives, although some were financed by the state. Among the latter were nautical training schools (from 1842), forestry secondary schools (from 1860), and agricultural colleges (from 1887) (Nilsson and Svärd 1991:5).

Among the other institutions that were involved in the creation and dissemination of skills and knowledge, we have already mentioned the Royal Swedish Academy of Science and the Swedish Ironmasters' Association. Several new organizations emerged during the 1860s, e.g. the Swedish Association of Engineers and Architects and the Stockholm Engineering Association. The Swedish Academy of Engineering Sciences, the Wood Pulp Association, and the Swedish Institute of Metal Research were added during the 1910s. These institutions were closely in touch with scientific research and technical education, and they played - and continue to play - a significant role for the diffusion and dissemination of technical skills.

It is difficult to find accurate measures of the importance of these different types of investment in skills and human capital. However, it is clear that the supply of skilled increased steadily from the 1850s. The number of engineers educated at the higher technical institutes amounted to about 700-800 in 1850, and some 2,000 in the late 1890s. The number of engineers with secondary education also reached about 2,000 at the end of the 19th century (Ahlström 1992: 9).

Moreover, the founders and leaders of several of the most successful Swedish companies were educated at the technical institutes and had received foreign training that was paid by the state or some of the institutions discussed above. For instance, Hans Tore Cedergren, who played a central role for the emergence of the Swedish telephone industry, and Gustav de Laval, founder of AB Separator in 1883 (known as Alfa-Laval from 1963) were educated at the Technological Institute of Stockholm. Gustav Dalén, manager and chief engineer of AGA, was a graduate of Chalmers, and Sven Winquist, founder of SKF, had been educated at the technical college of Örebro. Lars Magnus Ericsson, the founder of the telephone company still carrying his name, had received state grants for studying the electrical engineering industry in Germany and Switzerland company, as had most other leading industrialists in the country.

Ahlström (1992, 1993) argues that the successful innovators and entrepreneurs illustrate that there existed a network between the technical institutions, industry, and government already from the middle of the 19th century, and that this contributed significantly to the success of Swedish industrialization. The networks were of central importance for the development of industry, especially after the 1880s, when products became more differentiated and goods such as pulp, paper, and engineering products became more important. Until the inter-war period, these networks substituted for specialized research and development departments in many firms.

The importance of education and labor skills for industrial success has not diminished since the early era of Swedish industrialization. On the contrary, the increasing supply of skilled labor has generally been considered as one of Sweden's main comparative advantages during the last decades. Apart from a well-developed educational system of the classical type, attention has also been called to the existence of large scale vocational education programs (Nilsson and Svärd 1991).

Swedish vocational education dates back to several schools started during the 19th century, as we have noted above. Yet, the real growth in the area did not start until the 1920s, when the state became more engaged in the provision of vocational education. The number of people involved in vocational training programs increased rapidly during the 1920s and 1930s, partly because of persistent unemployment: special courses were arranged for unemployed youths. However, the system was criticized because the courses focused more on upholding the moral of unemployed people than on useful vocational skills (Nilsson and Svärd, 1991, p. 6). From the 1940s and 1950s, however, the system changed. There was a shift from manual to more intellectual skills, which meant that most courses included general education as well as specific training, and full-time courses became more common. The quantitative explosion of vocational education can easily be illustrated with some figures. In 1950, some 15,000 people graduated from full-time vocational courses lasting at least one semester. By the late 1960s, the number had increased to over 100,000 (Nilsson and Svärd 1991:18).

Institutional Change.

Several of the institutional changes that contributed to the industrial revolution have already been mentioned, e.g. the establishment of property rights for forest land, trade policies, and the support to education and science. Another notable reform was the introduction of Limited Company laws in 1848. This made it possible to raise more capital and take risks, which was necessary as the rate of technical change increased during the second half of the century. Earlier, most firms had been owned or at least dominated by one single family, and the owners were personally responsible for the firm's debt (Larsson, 1991:32-33). Limited companies - where the owners' stake was limited to their share of the firm's initial capital - employed 45 percent of the industrial labor force in 1872, and 80 percent of the labor force in 1912 (Hallvarsson, 1980:19).

Moreover, credit markets and banks emerged during the second half of the 19th century. The development of the banking sector was supported both by the export booms and by the construction of the Swedish railroad network. The railroad system was largely financed with foreign capital, and several of the larger commercial banks were employed by the state to sell Swedish government bonds abroad. At the end of the 1870s, the Swedish financial system comprised 35 commercial banks with offices in 160 cities, which was comparable to the most highly developed nations in the world

(Larsson and Olsson 1992). It is interesting to note that the foreign debt built up to finance the domestic infrastructure investments was comparable to the present debt burden of many developing countries. For instance, the interest payments to foreigners amounted to 10 percent of export value in 1908 (Hallvarsson 1980:26). The eventual repayment of the debt also illustrates the importance of chance and luck for long-term development. Most of the debt stock was denominated in German marks and French francs, and the heavy depreciation of these currencies after the first World War reduced the value of the outstanding liabilities to very modest amounts.[3]

[3]The importance of chance is also reflected by the sizable Swedish migration to America during the second half of the 19th century. This made it possible to urbanize at a rate that was consistent with industrial development. It is estimated that a quarter of the Swedish population (1.2 million people) emigrated between 1850 and 1910. As a result, Sweden avoided the worst problems related to rural poverty and mass unemployment: it is also likely that this helped avoid political problems caused by polarization between left and right. See further Haavisto and Kokko (1991).

3 THE EMERGENCE OF THE NORDIC TELECOM INDUSTRY

Although the traditional raw material based industries have been able to maintain their strong positions in Sweden and the other Nordic countries over the years, the Nordic economies have been in a process of fundamental structural change since the early 1990s. The raw material based industries were then quickly overtaken by the rapidly growing information and telecommunications sector. The frontrunners, companies like Nokia and Ericsson, have not only become strategic actors in the Finnish and Swedish economies, but have also gained considerable international fame. For instance, in early 2000, Nokia joined the ranks of Microsoft, Cisco and General Electric in the top ten list of the world's most valuable companies.

The step from raw material based industry to high-tech activities like telecommunications and information technology may appear large, but we will argue below that there are important similarities between the two. In particular, knowledge and human resource development – in the form of well developed knowledge clusters, as in the mature forest industry, or in the form of in-house assets, as in the early stages of Nokia's and Ericsson's breakthrough in the mobile phone industry – have been essential for success in both sectors. While it is not possible to systematically create innovations, like the NMT and GSM technologies that propelled Nokia's and Ericsson's breakthroughs, it is possible to systematically prepare for those commercial and technological opportunities and challenges that will inevitably occur. Both Nokia and Ericsson were well prepared when the pivotal innovations emerged, and could therefore exploit the opportunities that opened up.

The following section outlines Nokia's development from a raw-material based conglomerate to a high-tech telecom producer, with some focus on how the skills and knowledge needed for a high-tech breakthrough have been acquired. Section 3.2 points to some of the factors explaining Ericsson's success.

3.1 Nokia

Nokia is today best known for its mobile phones and telephone systems, but telecommunications has not been at the core of the company's business for more than about a decade. Yet, the history of Nokia reaches more than 100 years back in time. In 1865, the mining engineer Fredrik Idestam established a groundwood mill in Tampere in southwestern Finland, expanding it in 1869 to the nearby village of Nokia. There, the river Emäkoski provided the energy needed for Idestam's business venture, Nokia Ltd, which soon became Finland's largest pulp and paper mill. Some decades later, in 1898, the newly established Finnish Rubber Works also set up production at Nokia, attracted by the hydropower resources of the Emäkoski rapids. In 1912, Finnish Cable Works was established in Helsinki, to supply the cables and wires needed for the electrification of the country's emerging industrial sector. In all three cases, much of the relevant technology was imported. Idestam had studied the pulp technology during his travels in Germany in the early 1860s. The engineer Antti Antero, long-time manager of Finnish Rubber Works, had studied a Russo-French rubber factory in Riga, Latvia, Arvid Wikström, founder of Finnish Cable Works, had studied Werner Siemens' innovations in cable production technology in Germany. All three companies rapidly managed to gain a strong position in the domestic Finnish market, as well as a foothold in the large

Russian market: before independence in 1917, Finland was a Grand Duchy under Russian rule.

These three companies are the predecessors of today's Nokia. In 1918, Finnish Rubber Works acquired the majority of the shares in Nokia Ltd, to secure access to the hydropower resources at Nokia. Some years later, the new conglomerate also took control of Finnish Cable Works. Although a merger of the three companies was discussed already during the 1930, it was not realized until much later, and the three companies were allowed to develop independently during the following decades. All three were successful. Nokia Ltd became a large conglomerate producing electric energy, pulp, and paper, mainly toilet paper. Finnish Rubber Works produced rubber boots and car and bicycle tires, with the development of the world's first winter tire as a particular success. Finnish Cable Works posted the most impressive performance of the three, partly as a result of Finland's war repatriations to the Soviet Union after the Second World War. The bulk of war reparations were made in the form of industrial products, and Soviet demand exceeded the surplus capacity of Finnish industry. However, the lack of hard currency had led to strict import restrictions which made it hard to raise production capacity: instead, productivity increases were necessary to manage the war reparations. By the time the war reparations were completed, the Cable Works had not only been forced to improve productivity, but it had also secured a market in the Soviet Union that was able to absorb almost unlimited amounts of cable and wire. The existence of what seemed like a secure export market was a strong motive to increase capacity as soon as the post-war currency restrictions were lifted. Diversification was also possible: an electronics department with a group of R&D engineers was established in 1960, and resulted in the development and production of a variety of electronic goods. For instance, in 1962, Finnish Cable Works developed a prototype radiotelephone at the request of the Finnish Army (in competition with the country's two other leading electrical engineering firms Salora and Televa and the Swedish producer Sonab). The Army was eventually not able to place any orders due to cuts in the defense budget, but the companies found other customers. Televa's radiotelephones were sold to the Finnish police force, Salora sold to the coast guard and the state railway company, while Cable Works supplied the Postal authorities and exported successfully to the Soviet oil and gas industry (Pulkkinen 1997:75).

Nokia Corporation

In the mid-1960, the suggestion to merge the three companies came up again. Although there were good reasons for a merger – in particular, all three had outgrown the home-market and were hesitant to take on Western export markets on their own – there were also problems and risks involved. One problem was structural: there were clear synergies between cables and wires, electronics, and rubber products, but it was unclear how pulp and paper would fit in. Another complication was the difference in enterprise cultures. Unlike Nokia Ltd and the Rubber Works, Finnish Cable Works was a modern and reasonably dynamic company. It was also felt that the management of Finnish Rubber Works in particular was less flexible and more hierarchical than the others, with frequent conflicts and strikes as a result (Bruun and Wallén 2000:17-19).[4] Still, the outcome was a

[4] Another complication was that Finnish Rubber Works was closely tied to Finland's Swedish-speaking community through its bank, Föreningsbanken, while Nokia AB was

decision to merge all three companies into Nokia Corporation in 1966, under the leadership of Cable Works' CEO, Björn Westerlund.

Nokia Corporation was organized in four divisions: Paper, Cable, Rubber, and Electronics. The electronics division was the smallest of these, with only 460 employees and 3 percent of the conglomerate's total turnover in 1967. The fastest growth during the 1960s and 1970s occurred in the Cable division, but significant resources were also invested in the Electronics division. In particular, the research department was given generous funding for product development, although its profitability was very low or even negative for a long time. Yet, Nokia's CEO Westerlund made sure that the electronics workshops had access to the latest technology, and protected the division's independence against criticism from the board of the Cable division, who argued that the entire Electronics division should be closed down (Bruun and Wallén 2000:22).

In addition to his long-term support to the Electronics division, which would eventually develop into the Nokia we know today, Westerlund was also instrumental in setting up a strategy for Soviet trade. Soviet demand for cable, radio telephones, rubber boots, and other Nokia products appeared unlimited during the 1960s and 1970s. After the first oil crisis in the early 1970s, so did Soviet import capacity. The trade between Finland and the Soviet Union was essentially barter trade, with the Soviet Union supplying oil and other raw materials in exchange for industrial products. The massive increases in the international oil price after 1972 translated into corresponding increases in the Soviet Union's ability to pay for imports (Haavisto and Kokko 1991). Many Finnish companies, including Nokia, became increasingly specialized in Soviet trade – altogether, the Soviet Union accounted for more than one-fifth of Finland's external trade until the 1980s. However, Nokia's Soviet export potential was significantly larger than the actually realized exports. To avoid becoming dependent on the Soviet Union, Westerlund insisted that any increases in Soviet trade should be matched by increases in trade with the West (which in practice meant a restriction on exports to the Soviet Union). When he resigned as CEO in 1977, handing over control to Kari Kairamo, half of Nokia's exports were directed to the socialist block, with the other half going to the West. Many large Finnish export companies that failed to implement similar restrictions for the lucrative dealings with the Soviet Union ended up in severe crisis in 1991, when Soviet trade collapsed.

To become a high-tech company

When Kairamo took over Nokia in 1977, it was Finland's largest private company, with around 16,000 employees (or about 2 percent of the country's industrial labor force). At this time, Nokia was still primarily a producer of paper, tires, and cable, but Kairamo was committed to change this and to transform Nokia into a leading high-tech company. The foundation was already in place, in the form of Nokia's Electronics division, which had managed to diversify significantly during the preceding decade. The production of radiotelephones had expanded when a nationwide public radiotelephone system had been established in the early 1970s. Since the late 1960s, there had also been discussions about the establishment of a Nordic mobile telephone network, and an open standard for

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connected to Kansallisbanken, the bastion of Finnish-speaking capitalism. The compromise was that the two banks were given equal ownership shares and equal influence in Nokia Corporation.

telephones, base stations, and exchanges had been agreed in 1976. The cellular NMT network that was to be launched in the early 1980s in all the Nordic countries pushed Nokia (as well as the other Finnish producers Televa and Salora) to develop new products for what was expected to be a rapidly growing market. Nokia had also been marketing Siemens, Bull, Elliot, and Honeywell computers in Finland since the late 1960s, and had found a market adapting foreign computer equipment into package solutions for domestic industrial customers, e.g. the nuclear power plants built in Finland during the 1970s. By the late 1970s, the learning process had been successful enough to allow Nokia to produce and market its own computer terminals. Focusing on industrial customers, like banks, the postal service, and large retail chains, Nokia computer terminals and cash registers actually came to dominate the Nordic markets in the 1980s. By that time, Nokia had also managed to develop a very successful portable microcomputer that seriously challenged the dominance of Apple computers in the Nordic market.

But capturing the Nordic market was not enough for Kairamo, who had more ambitious plans for the company. Internationalization was the key objective. The problem was that Nokia could hardly develop into a leading international player in high-tech industry if it was to rely solely on internally generated growth. The company was too small, and although the Electronics division had been reasonably successful, it still lacked the necessary skills and experience to take on the world market. It was therefore necessary to focus on alliances and acquisitions to secure the strategic resources needed to grow large enough to compete with the large European, Japanese, and American incumbents in the international electronics market. This strategy was played out in two areas: telecommunications and televisions.

Telecommunications

In the 1970s, Finland had three major actors in the telecommunications industry: Nokia, Salora, and Televa. Salora, which had televisions and other consumer electronics as its core business, was the market leader in radiotelephones and had a 30 percent market share in the Nordic region. Salora's main sales argument was a technically advanced telephone that could operate on a larger number of channels than those of the competitors. Televa, which was state-owned, was stronger in telephone systems. In particular, Televa had been developing computerized telephone exchanges since the late 1960s. Unlike Siemens, Ericsson, and other large competitors that focused on analogue technology in the early 1970s, Televa was experimenting with both analogue and digital systems already from the outset. However, the project to develop a digital telephone exchange did not receive much support from company management. It was run by the young engineer Keijo Olkkola and a handful of colleagues, who were struggling to maintain the financing of the project. Bruun and Wallén (2000:49) report that the financing for Olkkola's research team was cut in each year's preliminary budget, only to be "temporarily" reinstated after heavy lobbying by Olkkola. In 1973, Televa's management finally presented an ultimatum to the project team. All financing would be stopped unless a buyer was found. After difficult negotiations, an agreement was made the same year to supply a digital exchange to a small 700-person municipality in the archipelago of southwestern Finland, Houtskär. This deal secured the future for the DX-200 switchboard, which eventually became an essential component in Nokia's GSM systems.

Meanwhile, competition with Salora pressured Nokia to improve its radiotelephones, and important technical improvements were made during the 1970s. For instance, Nokia introduced a duplex filter that allowed both parties in a radiotelephone conversation to speak at the same time – the earlier technology had only allowed one party to speak at a time, ending each statements with "over" to signal that the other party could respond. The challenge from the new NMT system that would be introduced in the early 1980s, however, seemed hard to handle. The three Finnish radiotelephone producers and Swedish Ericsson were not the only ones busily engaged in product development for the NMT system. The standard was several years ahead of developments elsewhere in the world, and most leading companies – including Siemens, Motorola, Hitachi, NEC, and Mitsubishi – had decided to enter in order to stay on the frontier.

Discussions about collaboration between Nokia and Salora had therefore started already in the mid-1970s, and in 1979 the two companies decided to establish a joint venture, Mobira, to pool their research and development resources. By this time, Salora was pressured by severe financial problems and there was little doubt that Nokia was the dominant partner, although formal ownership was shared equally. The initial aim was to capture a 50 percent market share in Finland and 20 percent in the other Nordic countries, but Nokia's CEO Kari Kairamo also argued that the company should not settle for market leadership at home, but instead aim for the European and world markets. To begin with, being big in the North meant being a global player, since the Nordic countries accounted for half of the world's cellular phone sales until the mid-1980s.

After the first few years, the challenges increased. Nordic proposals to adopt the NMT as a European standard were rejected in favor of national standards that largely aimed to protect national producers. Five major analogue systems emerged: in addition to the NMT (which was also adopted in Australia and several Asia-Pacific economies, as well as in Eastern and Central Europe), the main ones where the Japanese NTT, the US AMPS (which was adopted throughout the Americas and in parts of Asia), the UK TACS (which was used in Ireland, Italy, Spain, the Middle East, and the Far East), the German C-NET (also used in South Africa and Portugal), the Italian RTMS, and the French RC-2000. All of these systems were mutually incompatible. To become a global player, it was therefore necessary for Nokia (that had bought Salora's shares in Mobira already in the early 1980s) to adapt to a multitude of standards. It turned out that Nokia was the only European manufacturer to aim for a global market in the 1980s.[5] The large European companies Alcatel, Ericsson, and Siemens restricted their operations to the Nordic and Continental European standards, staying out of the AMPS and TACS markets (Pulkkinen 1997:104). The decision to compete head-on with Motorola and the large Japanese manufacturers from the very beginning was perhaps the clearest expression of the management's ambition to become a global company. It was believed that the tough competition and the need to adapt to all the different mobile phone standards would force the company to acquire the skills needed to succeed at a global scale.

[5] The brand name Mobira was changed to Nokia-Mobiar in 1986, and survived until 1989, when the telecommunications division began to use the Nokia brand, signaling the gradually increasing importance of this business area for the entire Nokia conglomerate.

In 1984, Nokia bought the rest of the consumer electronics producer Salora. The acquisition of Salora's assets – in addition to technology, Salora had also cumulated much competence in distribution and marketing of consumer electronics – was of great importance for Nokia's subsequent success in digital cell phones in the 1990s. In the mid-1980s, Nokia also entered into several other alliances in phone production. One of the most important ones was a joint venture in 1984 with US Tandy corporation, which marketed Nokia phones through its Radio Shack outlets. Nokia and Tandy also established joint production of cell phones in South Korea. Arguably, Nokia benefited greatly (and learned much) from Tandy's competence in cost-efficient production design and from its sales and marketing skills (Pulkkinen 1997:152). The acquisition of the UK-based Technophone in 1991 was another notable event. Technophone had production in the UK and Hong Kong, and an export network covering 40 countries, in many of which Nokia's own distribution system was weak. Morover, Technophone was considered a more efficient producer than Nokia, with shorter manufacturing times and lower labor utilization rates (Pulkkinen 1997:138).

Regarding telephone systems, Nokia had little in-house capability until the mid-1970s. The increasing demand for computerized telephone exchanges forced Nokia to send a research team to Alcatel in France to learn all that was needed to start license production of Alcatel's new digital exchanges in Finland. This meant that Finland suddenly had two companies developing competing digital exchanges: Televa with Olkkola's small research team, and Nokia with its French technology. The Finnish post and telecommunications authority argued that this was not feasible in a small country like Finland, and encouraged the two companies to collaborate. The result was a joint venture, Telefenno, owned in equal shares by Nokia and the Finnish state. Nokia's first demand was to discontinue Olkkola's digital exchange project so that Telefenno could focus on the existing Alcatel system. Only the existing contract with the small Houtskär municipality saved Olkkola's DX 200 project.

To begin with, Telefenno marketed three different systems: Telefenno's analogue exchange, Alcatel's digital exchange, and the DX 200 system, which was not yet in production. The choice between these three was decided largely by the Soviet preference for Olkkola's system. The domestic Finnish market was small, and the export potential in the tightly regulated Western markets was very limited: almost each country had a domestic producer that was protected by national preferences in public procurement. Hence, it was believed that the only opportunity to achieve economies of scale in production was to sell to the Soviet Union and other east block countries, and a preliminary export contract was signed already in 1977. The successful introduction of the DX 200 in Houtskär in 1980 confirmed that the choice to focus on the domestic solution had been right. A short time after the introduction of the exchange in Houtskär, orders came in from the telephone companies in Helsinki and Tampere, Finland's two largest cities. By 1984, DX 200 had 50 percent of the Finnish market. Nokia had not had any part in the development of the first NMT system that was introduced in 1981, but the second generation of the NMT, introduced in 1986, was largely based on the product. Nokia's GSM systems that took over in the early 1990s also include DX 200 as an essential component. Much of the development work for the GSM technology was done in collaboration with Alcatel, which had already established a relation with Nokia in the 1960s, and the German AEG.

The acquisitions and strategic alliances that were made during the late 1970s and 1980s were of central importance for Nokia's transformation from a raw material-based to knowledge-based high-tech company. Another component was a broad push for human resource development within the company. One part of CEO Kairamo's internationalization program was to encourage as many as possible of Nokia's Finnish staff members to gain international experience by working in Nokia's foreign affiliates.[6] Another area was formal education. Kairamo was engaged in several ventures to improve the Finnish (and European) public education system, which was considered bureaucratic and old-fashioned. Among other ideas, Kairamo emphasized the need for broad international student exchange programs, stressed the need for continuous, life-long learning, and called for close collaboration between industry and academia. The most tangible result was the establishment of "Nokia University". This was a comprehensive and ambitious education program managed by several Finnish universities in collaboration with Nokia, with the aim to raise the formal competence of all Nokia employees by one level. Bachelors were encouraged to obtain Master's or Licentiate degrees, and Masters and Licentiates were expected to aim for Doctorate degrees. The increase in the level of human resources was essential for Nokia's ability to absorb and diffuse the skills and knowledge that were obtained through acquisitions and strategic alliances during this stage of Nokia's development.

Taken together, this meant that Nokia was well prepared for the future development of the global telecom market by the late 1980s. The company was, in competition with Motorola, the world's largest mobile phone producer during 1986-1989. Nokia had also been the first to present a mobile telephone that could reasonably fit in a pocket, the Mobira Cityman. About a quarter of the world's NMT telephone systems were supplied by Nokia. The company had developed or acquired both the technical skills and the marketing, sales, and distribution skills needed for a global breakthrough. But there were also problems. Mobile phones and telephone systems accounted for less than 15 percent of Nokia's turnover.[7] Cables, rubber products, and forest products were more important. The quantitatively largest part of Nokia's business, however, was consumer electronics, in particular TV sets, and information technology (e.g. computers). The drive to make Nokia had not been focused on telecommunications – it was hoped that Nokia would make its breakthrough as a television and computer producer. Instead, these business areas nearly caused the collapse of the entire company.

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[6] Kairamo argued that not only Nokia but all of Finland should become more outward oriented, which made him a strong proponent of Finnish membership in the European Community long before this was a politically correct view. In this context, Bruun and Wallén (2000:37) report that Kairamo's vision was "to see a Finnish name in the passenger list every time an airplane crashes somewhere in the world".

[7] Thanks to the very lucrative exports of DX 200 telephone exchanges to the Soviet Union, it is likely that the share of profits was significantly higher, but there are no detailed data on Nokia's earnings from Soviet trade.

Televisions

Although Nokia's Electronics division had recorded some success in the development of computer terminals and monitors for industrial customers in the mid-1970s, Nokia turned down an offer to buy the debt-ridden television producer Salora in 1977. The main argument against the deal was that Nokia lacked experience from Salora's main business area: consumer electronics. The Electronics division was used to producing, marketing, and selling customized solutions to large industrial clients – mass production and marketing to hundreds of thousands of private customers were not on the agenda. However, times changed rapidly. Nokia's successful development of stationary and portable PCs introduced new marketing challenges. The success of the NMT system pushed Nokia in the same direction: although mobile phones were sold in tens of thousands rather than hundreds of thousands of units, most customers were private consumers buying a single set rather than companies or institutions buying larger amounts.

After the establishment of the Mobira joint venture in 1979, Nokia had also learned more about Salora. When a new offer to buy Salora came up in 1984, it was therefore decided that Nokia would enter the consumer electronics field at a large scale. Salora was not the only acquisition in this field. In rapid succession, between 1984 and 1987, Nokia bought three other television producers: Swedish Luxor, French Oceanic, and German Standard Elektrik Lorentz. By 1987, consumer electronics accounted for more than a quarter of Nokia's turnover Nokia was Europe's third largest and the world's ninth largest producer of television sets. As in the mobile phone business, Kairamo argued that it was imperative for Nokia to internationalize rapidly and to meet the main competitors face on.

Nokia's activities in computers and information technology expanded in the same way. The main acquisition in this area was the take-over of Ericsson Information Systems in 1987. The Ericsson division had itself acquired companies like Facit and Data-Saab some years earlier. The new company, Nokia Data, was one of Europe's largest computer companies, employing over 8,000 people and accounting for over 20 percent of the Nokia group's aggregate turnover.

The heavy investments in consumer electronics and information technology suggest that Nokia's management saw this as the company's future core business. This was a massive miscalculation. The European market for television sets was saturated, and in particular the German Lorentz was generating large losses. Other backlashes followed. Several leading members of the mobile phone division left the company in 1988, after a conflict with the CEO, Kairamo. Rumors about a merger with Volvo, or even a sale of the telecom operations, flourished. The return on the investments in the US market was falling. The suicide of Kairamo in December 1988 seemed to be the low point in the company's history. But things became worse.

Although Nokia's mobile phones and telephone exchanges generated substantial profits during the following years, the expenditures were also huge. The losses from the consumer electronics division were as large as the profits from the telecom side. In addition, massive R&D expenditures were needed for the development of the digital GSM system. The period from 1989 to 1992 can be characterized as a struggle for survival, which culminated in 1991. That year was not only marked by the beginning of the severe banking and financial crisis in Finland, but also by the collapse of the Soviet

Union. This cut severely into Nokia's cash flow, and forced the new CEO, Simo Vuorilehto, to extreme measures. In principle, all of Nokia was put up for sale. Thus, Nokia's Paper division was sold to the American JA/Mont in 1991. The Rubber division was also sacrificed. The tire production was sold to Japan's Sumitomo, while footwear production was spun off into a separate company. To cover the losses in the consumer electronics division, Nokia Data was sold to the UK-based company ICL (owned by Fujitsu) in 1991. The rest of the company was offered to Swedish Ericsson for a fraction of Nokia's present market value. Ericsson was willing to acquire Nokia's mobile phone and telecommunications divisions, but eventually declined the offer when it was told that consumer electronics – read televisions – must also be included in the agreement. All in all, Nokia shrunk from 44,000 to 22,000 employees during Vuorilehto's three and a half years as CEO, from the beginning of 1989 to middle of 1992, when he was succeeded by the current company president, Jorma Ollila.

Nokia's recovery: GSM and design

The turnaround for Nokia came with the breakthrough of the digital GSM technology in 1991 and a simultaneous turnaround in Nokia's mobile phone design strategy. Nokia had begun the development of its first GSM network (largely on the basis of the DX 200 switchboard) in 1987, when it entered into an alliance with Alcatel and AEG. The first orders came from France and Germany in 1988, with operators in Austria, the Netherlands, and Finland following the year thereafter. By 1990, new orders were flowing in. European integration was an important factor in enlarging the market for Nokia. The Single Market program stressed the need to raise the level of competition in Europe, and most countries licensed several operators for the new GSM systems, all of whom needed to set up their own networks. Increasing openness in public procurement also contributed to enlarge the international market.

The first of these new GSM networks was inaugurated in Finland in July 1991 by Nokia, and the first phone calls were made with Nokia's new digital cell phones. The following year, Nokia delivered GSM systems to 7 European countries as well as Australia, New Zealand, and Hong Kong. At the same time, orders for the old NMT systems continued coming in, mainly from the former Soviet Union and the East and Central European transition economies.

It was clear that the construction of new networks would also lead to increased demand for phones. At the end of 1991, there were an estimated 13 million mobile phones in the world, and Nokia's forecast was that the number would double each of the following years. More capacity was therefore needed. Nokia has already set up a new production line adjacent to the Lorentz factory in Bochum, Germany, and now British Technophone, Europe's second largest mobile phone producer, was also acquired. Several new products were also introduced.

Up until about this time, Nokia's advances in mobile phone production had largely been driven by technological progress. The size of phones had been reduced at a steady rate, from the large and clumsy "luggable" car phones of the early 1980s to "transportable" phones in the mid-1980s, and hand portable phones shortly thereafter. Each new model had been smaller than the previous, and therefore "more" mobile and portable. By the early 1990s, the size of mobile telephones had been reduced to a few hundred grams, with most manufacturers focusing their marketing efforts on the size and technical characteristics of their product. With its NMT 101 phone that was

presented in January 1992, Nokia made a U-turn in its marketing strategy. Design and aesthetics were the new sales arguments, and Nokia started targeting the mass market rather than the professional businessmen ("yuppies") that had been the standard customers.[8] Optional colored phone covers were introduced later the same year. The phone became a great success, and helped Nokia recover the market shares that had been lost during the preceding difficult years. Several new models of GSM telephones, typically with innovative design and strong focus on consumer needs, were introduced during the following years, and by the mid-1990s, Nokia had managed to transform the mobile phone from an exclusive capital good to a differentiated consumer good. To begin with, Nokia had little competition in the GSM phone market. Motorola maintained a focus on analogue technology several years longer than the European producers. A British attempt to establish a new manufacturer, Orbitel, failed. The toughest European competitor, Ericsson, focused more on systems than phones. Arguably, Nokia's head start in the GSM field gave it the advantage necessary to become the market leader for the remainder of the 1990s. Nokia has not recorded any losses since 1992.

Under Ollila's management, Nokia has continued focusing on telecommunications. The Cable division was sold in 1996 to the Dutch NKF Holding. The production of televisions was rationalized. In 1992, Nokia's television production had employed 6,000 people in 6 factories. By 1994, only two establishments remained, in Turku, Finland and Bochum, Germany, with some 3,000 employees. In 1996, the Bochum establishment was closed, and the Turku factory was finally sold, to Hong Kong-based Semi-Tech. The only part of Nokia's consumer electronics investment remaining in the company is a multimedia production unit in Turku. The four divisions that make up today's Nokia are Nokia Networks, Nokia Mobile Phones, Nokia Ventures Organization (financing various applications and software development for Nokia's products) and Nokia Research Center. The focus on telecommunications has been an enormous success. By the year 2000, Nokia had grown to more than 55,000 employees throughout the world. The stock market value of the company had increased from around 1 billion USD in 1990 to over 230 billion USD in 2000, totally dominating the Finnish corporate sector: Nokia alone accounted for over 60 percent of the value of the entire Helsinki stock market, and nearly a quarter of the country's exports.

Ollila also brought back some of the focus on human resource development and life-long learning that was lost during the crisis years before 1992. As a result of the structural changes in the company – the expansion of the telecom activities and the sale of everything else – Nokia has managed to raise the average education level (and reduce the average age) of its staff dramatically. The recruitment of skilled engineers to the expanding telecom divisions has been facilitated by close collaboration between Finland's universities and Nokia (as the former CEO Kairamo demanded). The risk that Nokia may concentrate its strategic activities outside Finland if it cannot find enough skilled professionals in Finland has been used to justify heavy investments in higher technical education. Nokia has also contributed significantly to the external financing of university research. In fact, while most academic areas have barely recovered from the

[8] An illustration of this is Nokia's campaign for the NMT 101 in the US. "The Japanese made the smallest. The Americans the lightest. But the Finns made the best." See Pulkkinen (1997:119).

budget cuts made during the Finnish crisis years in the early 1990s, there has been massive expansion in electrical engineering, information technology, and related areas.

Success factors

Summarizing some of the determinants in Nokia's transformation from a raw material based to a knowledge based high-tech company, it appropriate to put particular emphasis on two factors that were noted already in the discussion of the forest industries' long-term sustainability. Firstly, it is clear that the acquisition of knowledge and skills has been of central importance for Nokia's breakthrough. Unlike the mature forest industry, where much of the skill and knowledge is created in the industry's knowledge clusters, the telecommunications industry has not developed any similar institutional structure yet. Nokia has therefore been forced to internalize these processes, systematically acquiring the skills needed for further stages in research and product development. At the same time as new knowledge has been brought into the corporation, there have also been comprehensive efforts to raise the educational level of existing staff. The establishment of *Nokia University* in the 1980s and the emphasis on individual development and life-long learning during the past two decades have been essential for the diffusion of new technology throughout the company.

It is not until the second half of the 1990s that the telecommunications industry in Finland is beginning to develop the institutions for a knowledge cluster. Very substantial public investments in relevant higher education, the establishment of formal linkages between universities and industry, and industry-financed research organizations are contributing to the creation of a knowledge cluster. It is possible that this pattern – with in-house knowledge development in the early stages, and more focus on institutions and collaboration in later stages of an industry's development – can be generalized from the Nokia case to other instances where new technologies and new industries are established.

The investments in education and knowledge creation have also led to the establishment of several production clusters focusing on telecommunications and information technology. Although many of the new companies that have been established in these clusters are presently sub-contractors to Nokia, they may in the long run create a strong enough competitive advantage to reduce Finland's dependence on the market leader, Nokia.[9] In fact, Finnish innovation and technology policy is today considered among the most advanced in the world, partly because of Nokia. Finnish authorities have for a long time been concerned about how the national business environment affects the competitiveness of individual dominant companies like Nokia, at the same time as the have encouraged diversification and development of innovations and new companies.

The other central factor has been internationalization. Being a small country, it has been clear from an early stage that the domestic market is not large enough to support the development of a high-tech industry like telecommunications. In particular, it has been clear that the small domestic (or Nordic) market would not be able to carry the costs for the increasingly expensive R&D programs necessary to remain competitive.

[9] Nokia has itself been important in creating these clusters: the explicit aim of the Nokia Ventures Organization, one of the four divisions of today's Nokia, is to identify and support innovative companies in the telecom and information technology cluster.

The need to aim for the international market was therefore recognized early on. A side effect of the outward oriented strategy has been the need to measure up to foreign competition, which has pressured Nokia to utilize its resources efficiently. It has also been a precondition for acquiring the technological assets necessary to establish its own capacity in technology development.

There are also some more specific determinants of Nokia's success story. Pulkkinen (1997:164-165) emphasizes the relatively slow development of the cellular mobile phone market, which made it possible for a relatively resource-poor newcomer like Nokia to acquire the skills needed for sustainable success in the industry. For instance, Pulkkinen shows that the market penetration rates of video recorders and televisions reached around 20 percent 10 years after their first commercial launch. For cellular mobile phones, the market penetration rate in the US was still only 5 percent in 1994, 10 years after its first commercial launch.

Some specific characteristics of the Finnish (or Nordic) home market have also been important. Finland and Sweden have constantly been the top countries regarding the market penetration of mobile phones, which has naturally benefited the local producers. One reason is the peculiar institutional setup in the telephone markets in Finland. Rather than having only one national telephone operator (as most other Western European countries until the 1980s), Finland had numerous local telephone companies, and telephone subscriptions very extremely expensive in many locations. For instance, in Helsinki, a subscription could cost thousands of USD still in the 1980s, with long waiting periods. The emergence of the cellular phone introduced an attractive alternative: although the early generations of handsets were very expensive, they were still less costly than regular fixed line subscriptions. Another advantage in the Finnish market was the prohibition for domestic cellular operators to subsidize the handset (in many other countries, a handset may even be included without extra cost when new subscriptions are made – the costs will of course be paid through higher monthly fees). This encouraged Finnish consumers to be more sensitive to the cost, design, and performance of the handset, forcing Nokia to focus on these characteristics much earlier than producers in other countries (where consumers were less discriminating because they did not buy their phones directly). Hence, although most product markets today are highly globalized, it seems that local conditions and the local environment are still important determinants of where and how new industries develop.

Having said this, it is appropriate to note that Nokia's breakthrough in telecommunications also illustrates the element of chance and unpredictability that is an inevitable part of most (if not all) great industrial success story. The investments in learning, education, and internationalization that were made in the 1970s and 1980s did not aim primarily at launching Nokia as one the main players in the international telecom market. Instead, Nokia's management had its eyes set on the great consumer electronics markets, where televisions and computers were the main products. Most of Nokia's acquisitions during the 1980s aimed to strengthen the consumer electronics division, and much of the research effort was directed to the same area, e.g. to develop the high-definition TV technology. Most of these investments turned out to be disastrous, costing Nokia billions of USD in losses until the mid 1990s when the production of televisions was sold off, but they contributed to the development of the skills and the knowledge – both in production technology, marketing, and design – that were necessary to excel in the mobile phone industry. The tentative conclusion from Nokia's experience is that

success is perhaps a mix of systematic creation of skills and knowledge and random technological innovation. Although it is impossible, at least for relatively small players, to plan major technological breakthroughs in advance, it is possible to create an environment where the firm is well positioned to adjust to changing conditions and to benefit from innovations and market opportunities.

3.2 Ericsson

Unlike Nokia, its Swedish competitor Ericsson had firm roots in the telecommunications business when the modern cellular mobile phone technologies began to emerge in the 1970s. The company was founded already in 1876 by Lars Magnus Ericsson to produce telephones and switchboards. It became a multinational already in the 19th century, with Finland and Russia as the first foreign customers for its telephone systems.

During the first three-quarters of the 20th century, Ericsson´s core business areas were consistently telephones and switchboards for fixed networks. This background generated, of course, some knowledge to be used in the development of the mobile telecommunications area. However, important knowledge and experience also came from another industrial areas where Ericsson entered at an early stage: radio technology. In 1919, Ericsson formed, together with ASEA (now ABB) and AGA (gas equipment), a company called Svenska Radio Aktiebolaget (SRA). Radio broadcasting was starting in Sweden and SRA´s initial business was to build radio transmitters (see Meurling and Jeans, 1994). In 1921, SRA also began to make radio receivers for home use and it started its own radio broadcasting service (which had to close when the government broadcasting company was formed). SRA continued to build radio receivers into the 1950s, but also became involved in other applications of radio technology, both civilian and military. An airborne transceiver was build as early as 1920 and television-broadcasting experiments were carried out in Stockholm in the mid-1930s.

In the early 1960s, SRA sold off the radio and television production operations and concentrated on the defense business, with radar, troop radio, and land mobile radio business. Ericsson was the driving force behind these changes and became increasingly involved in the company's management. In 1983, SRA became a fully owned company within the Ericsson group and changed its name to Ericsson Radio Systems AB, referred to as ERA.

In the development of the Swedish mobile phone industry, Ericsson was not alone. Another important player was "Televerket", the Swedish Telecommunications Administration, which was a state-owned company. In the 1950s, Televerket not only owned and operated everything in Swedish telecommunications, but was also manufacturing many of its own products. Televerket and Ericsson had over the years worked very closely together in developing telephone equipment, and this cooperation was also crucial in the development of Ericsson's mobile phone division.

Televerket and SRA jointly developed the first Swedish mobile phone systems already in the 1950s, to be set up in Stockholm and Gothenburg, and continued refining its radiotelephone technology throughout the 1960s and 1970s. Yet, the big breakthrough did not come until the establishment of the NMT system in the 1970s. Some enthusiastic engineers from Televerket and SRA had in 1969 proposed the idea of a Nordic standard in the mobile area and the managed to get the governments in Denmark, Finland, Norway and Sweden to accept their proposal. The pan-Nordic automatic cellular mobile telephone system, which was an analog system, took ten years

to complete, and required a committed financier along the way. Ericsson was not very interested in investing in a "public good" (which is one way of looking at NMT and later generations of mobile systems), but Televerket was. With the exclusive rights to the market, Televerket could spend ten years in planning and developing a new mobile network. As noted earlier, parallel development work was underway in Finland and other countries.

The second-generation wireless standard, the digital GSM system, was the one that would make Ericsson a real world player. A research group, once again jointly set up by Ericsson and Televerket (and four of Sweden's major technical universities) was created in 1977 and during the next ten years the specifications for GSM was developed. Again, parallel processes were set up by Nokia and its collaborators on the European continent. The "mobile group" inside Ericsson, however, was not well recognized by the top management and the rest of the company. ERA lived its own life inside Ericsson, run by a small group of entrepreneurs (internally called "cowboys") that nobody in the company cared about. As one quote says: "So we didn't really know much about ERA. And we didn't care!" (Meurling and Jeans 1994: 48). ERA was even located far away from the rest of the Ericsson group – in Kista, north of Stockholm – so there was no day to day contact between them. Despite the neglect by the headquarter, the development of GSM was completed in 1988, but mobile phones were still considered a side-show within Ericsson – a product line kept in being by the need to support sales of mobile systems.

In the 1990s, with the breakthrough of the GSM technology, the top management finally recognized ERA and the importance of mobile handset production and started to invest heavily in developing new equipment. R&D spending jumped.from 11 percent of sales in 1990 to 24 percent in 1991 (Åsgård and Ellgren 2000). As a result, Ericsson generate exceptional growth during the 1990s. Annual net sales increased from SEK 45.7 billion in 1990 to SEK 215.4 billion in 1999 and worldwide employment grew from 70,000 to 103,000 employees (Meurling and Jeans 2000:393). In 1990, the business area of mobile telephone systems (including mobile phones) accounted for some 25 percent of the company's sales; in 1999, this had risen to 40 percent. Today, Ericsson has become one of the worlds leading suppliers of cellular infrastructure, mobile telephones (where actual production has recently been outsourced), and switching systems and fixed networks, with operations in more than 140 countries.

As was the case for Nokia, it is clear that part of Ericsson´s success in the mobile telephone business was related to its rapid internationalization. By adapting its equipment to different standards used in various countries, it could begin to look abroad for expansion. It managed to enter the US market very early and in 1998, it had become one of the three top cellular infrastucture suppliers, with about 30 percent of the US market (Meurling and Jeans 2000). The US success was repeated in the UK, Italy, Germany and Japan and soon Ericsson became a major player all around the world. This, of course, resulted in very significant economies of scale as well as a very competitive entrepreneurial climate: the entry into the largest foreign markets also meant that Ericsson chose to compete directly with its main rivals.

Trying to generalize Ericsson´s success in the development of digital mobile systems and terminals, it possible to outline at least four other factors that have been important for its success:

?? Ericsson's early experience with telephone and radio systems led to the accumulation of skills and competence in the relevant technology. At the same time, it should be noted that the lack of prior experience with consumer electronics and mass marketing may be one of the reasons why Ericssson's performance in mobile telephone handsets is weaker than its success on the systems side.

?? The close cooperation with Televerket, a state owned company, facilitated the long-term financing of the research and development costs for both the NMT and GSM technologies at their early stages of development, when risks were high and rewards were uncertain.

?? Very substantial amounts have been invested in R&D once technology standards have been established.

?? A few outstanding entrepreneurs have made significant contributions to technology development.

However, as in the case of Nokia, it is interesting to note that the outcome of all these efforts has not always been the intended one. When the entrepreneurs at Ericsson Radio System started to develop the NMT and GSM technologies, they were consistently ignored by the top management at the headquarters. The lack of interest in financing the development of the NTM system is perhaps understandable, considering the public good character of such a system. As soon as it is developed, many companies can deliver the equipment. But even after the system was invented, Ericsson was not very interested in the beginning to deliver the most modern equipment (Åsgård and Ellgren 2000). Instead, the focus of the company's operations remained in fixed line telephone systems. It was not until after Televerket threatened to buy the equipment for the NMT system from the Japanese that Ericsson reacted.

It should be noted in closing that the Swedish success in the mobile telecommunication sector is also to a large extent a cluster phenomenon. When Ericsson Radio System moved to Kista in the 1980s, this was a remote and empty place north of Stockholm. In order to minimize risks and costs, all innovation companies like Ericsson outsource an important share of their operations, and in the wake of Ericsson´s move to Kista, several of its sub-contractors followed. Ericsson's success in the mobile phone industry meant that many of these firms were also able to expand at a rapid rate. Today, Kista has developed into one of Europe´s largest clusters in information and telecommunication technology, where many of the institutions necessary to develop a knowledge cluster of the type seen in the forest industry are presently emerging.

4 SUMMARY AND CONLUSIONS

The purpose of this paper has been to describe and analyze the evolution of industrial competitiveness in Sweden and Finland in a long-term perspective. Section 2 looked at the foundations for industrial take-off in Sweden, with some focus on the development of institutions for the creation and dissemination of the skills and knowledge needed in the emerging industrial sector. Section 3 narrowed the focus, and examined the emergence of Finnish Nokia and Swedish Ericsson as market leaders in the high-tech mobile telecommunications industry. The emphasis here was on the transformation of Nokia from a producer of simple raw material based goods to a knowledge-based high-tech company.

Although the two sections have examined industrial development at different levels of aggregation and at different points in time, it is still possible to point to some common findings and results. These include the following:

?? Institutions and institutional reforms have played an important role for growth and development. Several examples have been highlighted throughout the paper. For instance, the land reforms in the early 19th century were essential for the introduction of new technology in agriculture: the subsequent increase in agricultural productivity was a prerequisite for industrialization. Similarly, the introduction of laws to guarantee re-planting and to limit the concentration of forest ownership in the early 20th century were essential to create a sustainable resource base. More recently, various environmental regulations have forced the Nordic corporate sector to take a leading role in the development of environmentally sustainable production technologies. The role of various public or semi-public institutions to promote research and knowledge diffusion has also been emphasized.

?? The acquisition of relevant skills and knowledge has been an essential success factor. The Swedish industrialization process relied to a great extent on foreign technology and capital. Foreign direct investment in Sweden was important, but the international experience of Swedish entrepreneurs and innovators also contributed significantly. The foreign technologies that were transferred to Sweden were rapidly absorbed in domestic industry, since the level of education was relatively high.

In the telecommunication sector, the acquisition of knowledge has largely taken place at the firm level. Ericsson's long experience in the telecom business allowed it to develop much of the necessary competence within the corporation, although collaboration has become increasingly important in recent years, as technology has become more sophisticated. Nokia's limited experience in the telecommunications field forced it to acquire a significant share of the necessary assets by buying up local as well as foreign companies, but in-house training and education have been of central importance for Nokia's ability to absorb new technology. Both companies have also benefited greatly from public investments in higher education and research.

?? Internationalization has been essential at all levels of development. The first stages of Swedish industrialization were clearly export-led, driven by the demand for forest products in Great Britain and other parts of Western Europe. Internationalization has also been essential for the Nordic telecom producers to finance the large fixed costs related to research and development. In addition, a relatively open trade regime has been necessary for the acquisition of modern technology, both at the early stages of industrialization and in today's high-tech industries: many of the core patents in the telecom sector are held by US, Japanese, and continental European producers. The need to adapt technologies to international standards and the continuos competitive pressure from other international producers have also been important driving forces in many industries, not least telecommunications.

?? The technological innovations underlying both Nokia's and Ericsson's breakthroughs were possible only thanks to long-term investments in R&D programs. In Nokia's case, early orders from the Soviet Union were essential to secure financing for technology development; in the case of Ericsson, support from the state-owned Televerket was instrumental. At the same time, it is clear that

focused long-term research projects are high-risk ventures. Neither Nokia nor Ericsson prioritized the R&D programs that eventually generated the innovations necessary for the successful development of the GSM technology. For instance, Nokia's primary investment emphasis was instead on projects that eventually failed, such as the HDTV program. An essential success factor has therefore been flexibility: both companies were able to shift rapidly from other activities to the mobile phone industry when it took off in the early 1990s.

?? While most of the industry's early development was based on in-house assets, it now appears that a knowledge and skill cluster is emerging in the telecommunication industry. It is possible that this suggests a general pattern in the development of new technologies or industry sectors. Intangible, firm-specific assets dominate the early stages of a technology's life cycle, whereas an increasing share of the essential knowledge and skills are of a "public good" character at later stages. Knowledge and skill clusters can arguably not emerge unless a large share of the essential knowledge and skills are available to most participants in the cluster. A central determinant of how "public" the knowledge and skills are may be the extent to which the public education system is involved the industry. In the forest industry, it obvious that the public higher education system plays a central role: this may be underway also in the telecom sector, as a result of the increased investments in relevant higher education.

A tentative conclusion from this paper is that an industry's success is a mix of systematic knowledge creation and random technological innovation. It is not possible to systematically generate major technological breakthroughs, but it is possible to create an environment where firms or entire industries are well positioned to adjust to changing conditions and to benefit from innovations and market opportunities. In mature, raw material based industries – like paper or wood products – the innovations are likely to be incremental, and a large share may be related to changes in demand or international competition, rather than major changes in production technology. A solid knowledge base is, nevertheless, necessary to ensure the necessary flexibility and adaptability. In younger industries – like telecommunications – fundamental changes in technology will be more common, and the main challenges are related to the ability to acquire the technical skills necessary to remain competitive. Although mergers and acquisitions as well as various kinds of strategic alliances are likely to be important in these sectors, a solid knowledge base within is also essential to facilitate the dissemination and implementation of new technologies throughout the firm or industry.

These conclusions suggest an important role for public policy. The experiences discussed in this paper suggest in particular that public policy should provide an appropriate institutional framework to facilitate the sustainable use of land, raw materials, and other resources and promote *learning* and *internationalization*. While most successful companies invest heavily in in-house programs for knowledge creation and human resource development, it is essential that the public education system can also provide graduates with appropriate skills and knowledge. This is not only a prerequisite for successful life-long learning in the business sector, but may also provide a common knowledge base for the development of various networks and clusters in industry. Direct support to in-house commercial research, on the other hand, is more questionable. Although Ericsson's experience points to successful collaboration between the company and the Swedish public sector in the development of its NMT and GSM technologies, it is often a costly and inefficient way to promote a competitive

business environment. One problem is that direct state intervention distorts competition. Another problem is the risk inherent in any long-term R&D project: failures are more likely than successes.

Internationalization is best supported through open and outward-oriented trade policies. It has repeatedly been noted that access to export markets is essential for small-country producers, but it should also be pointed out that access to imports at competitive cost is perhaps equally important. Few countries can rely exclusively on domestic resources for economic development. A significant share of the cheapest intermediates and best technologies for any industry, even in relatively simple raw material based sectors, is likely to be found abroad. Outward oriented trade regimes will promote the flow of information about these resources, both through trade and foreign direct investment.

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