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1 Introduction

The point of departure of this paper is a general worry about the rather weak international performance of the Danish information and communication technology (ICT) sector. The main focus is that Denmark, on the one hand, is one of the most advanced user nations, measured by conventional indicators for user penetration, such as number of personal computers, mobile phones and Internet access per capita. It is on the other hand rather obvious that the country is not one of the major players on the international ICT markets, even allowing for country size. The nearby and somewhat similar countries of Sweden, Finland and the Netherlands, are living proofs that small countries can be highly visible in this field.

The purpose of this paper is to investigate the apparent paradox of advanced demand from Danish consumers, firms, and government agencies (such hospitals, schools, national as well as regional administration) versus a rather weak supply side in terms lack of international competitiveness in ICT equipment and services.

This mismatch is put forward and specifically discussed in relation to the position of the Danish ICT sector in 3G and next generation wireless communication standards.

The paper is structured as follows: ICT is looked at within an innovation system perspective in Section 2. Section 3 investigates the structure and performance of the Danish ICT sector in an international perspective. Some features potentially behind the weak Danish position in ICT manufacturing are highlighted in Section 4. The development of the demand pattern for 3G and fiber to the home ICT infrastructure is discussed in Section 5. This section also includes a discussion of the challenges for the Danish ICT sector in the next generation wireless standards. Section 6 presents the conclusion.

2 The interaction between advanced demand and supply

The effects of home markets on the evolution of national production and export patterns were studied already by Vernon (1966) who argued that the advanced demand in the US allowed domestic

producers to gain advantages in the early stages of the product life cycle. This has been followed by a range of work emphasising that producers and users located within a nation, region, or a close network tend to interact and thereby strengthen their capabilities. The role of demand in the innovation system is closely related to user-producer interaction. Being connected to advanced users will form a competitive advantage for both producers and users. In small open economies many patterns of specialisation reflect advantages based on close interaction between advanced users and producers, such as dairy technology in Denmark and paper and pulp machinery in Sweden (Lundvall, 1992); (see also Dalum, 1992; Fagerberg, 1992).

More emphasis is put on the quality of demand compared to the quantity because competent and demanding users have initiated innovations even in areas with small production volumes. Innovation and production are interdependent and innovation is one of the most important factors in shaping and restructuring systems of production. It may introduce new sectors, break down old ones and establish new links in the system of production (Lundvall, 1988). In the study competitive advantage of nations Porter (1990) found that home demand conditions had some effect in nearly all industries investigated. To a certain degree they have shaped the character of innovation and development of the domestic industry. He found that quality is more important than quantity in determining competitive advantage. Advanced domestic demand can place producers on a product trajectory that is different from other producers and can eventually turn out to be successful. Mowery and Nelson (1999) analysed the sources of industrial leadership based on studies of seven industries. They focused on the key role of users and international differences is the profile of domestic demand. Examples of the role of demand in the evolution of industries studied are semiconductors and machine tools (Langlois and Steinmueller, 1999; Mowery and Nelson, 1999).

The concept of lead users is closely related to this discussion. Von Hippel (1988) analysed the sources of innovation in several US industries and found innovative activity to be concentrated in a subset of users. The suggestions of these 'leaders' are often preferred by all users. He defined lead users as those who demand novel or enhanced products, processes or services that solve the needs that are going to be dominant in the market.

Lundvall (1985; 1988; 1992) is rather narrowly focused on the positive effects of user-producer interaction on producer innovativeness, user utility and, more generally, on the innovation system. The interdependence between users and producers acts, however, both ways. Users with weak technological competencies may have negative effects on the system because they may create disadvantages for the producers. Recently Lundvall has added to the features for successful user-producer interaction that innovators may benefit from having access interaction with a diverse set of users, because being locked in with a single user may represent a too narrow basis for interactive learning (Lundvall and Vinding, 2004). While the close user-producer interaction is beneficial in creating incremental innovations, it can also cause strong and established great firms to fail. Based on numerous case studies Christensen (1997) and Utterback (1994) found that the emergence of new disruptive technologies - that in the beginning were inferior to the existing ones, but later outperformed these - often emerged outside the industry and its usual customer base. The user-producer interaction lead the producers along technological trajectories that were outperformed by disruptive technologies.

The role of domestic demand clearly plays an important part in the evolution of industries. It can lead producers on a development trajectory that may prove beneficial, but also lure the producers into unfavourable positions. Lack of interaction or dominance of less competent users may lead to a vicious circle of development, while advanced and competent users may spur innovation and competitive advantage.

3 Structure and performance of the Danish ICT sector in an international perspective

In OECD (2000a) Denmark is ranked high in terms of ICT employment in comparison with 24 other OECD countries. Based on 1997 employment data Denmark had more than 96,000 ICT employees in almost 12,000 firms. The share of ICT employment in the business sector was 5.1% compared to an OECD (24) average of 3.6% and an EU average of 3.9%. The only countries with a higher share were

Sweden, Switzerland, Hungary, Finland and Norway. The distribution of the ICT employment shows that Denmark had a low share in manufacturing and telecommunications services and, consequently, a higher share in other ICT services (OECD, 2000a).

In Table I the 1997 data on employment and exports are assigned to six different ICT segments. Services account for approximately 80% of ICT employment and exports.

"Take in Table I"

In 1997 ICT manufacturing accounts for less than 2% of total Danish private sector employment and an even smaller share of exports. Communication equipment accounts for more than half of ICT manufacturing employment and less than 25% of its exports. In comparison, the Finnish and Swedish employment shares were higher, 4% and 3% of total private sector employment, respectively. But the differences in total ICT employment shares were not big. In Sweden it was almost 10%, while the Danish and Finnish shares were around 8.5% (Nordic Statistical Institutes, 2000). The service segment of Danish ICT is by far the largest measured by employment. The IT services and consulting segment is a subset of total ICT services. In terms of employment this segment is larger than the total ICT manufacturing activities, but in terms of exports it is less than two-thirds, which indicates that IT services and consulting are focused on the domestic market.

The Danish ICT sector experienced substantial growth in the period 1992 to 1998 in terms of turnover per employee (35%), employment (20%) and value added per employee (25%) - measured in current prices. Generally, value added per employee has increased faster than employment, indicating increased productivity or increased foreign direct investments. The employment increase can primarily be assigned to ICT services while ICT manufacturing has shown below average growth. However, the size and competitive performance of the aggregate ICT sector is weak in the international context. For a group of 15 OECD countries in 1997 only one, Iceland, had a GDP share of the ICT industries lower than Denmark (OECD, 2000b, Table 1)[1].

In terms of competitive performance, Danish ICT manufacturers lost market shares within the OECD market 1988-96. OECD imports of ICT equipment grew more than 120%, while Danish exports of ICT goods increased by 68% (Danish Agency for Trade and Industry, 2000).

The structure of Danish ICT manufacturing exports is shown in Table II. Export specialisation is a convenient measure for analysing the relative export structure of a country vis-à-vis the average pattern of a relevant group of countries. Among the countries shown UK and US are the only countries specialised in ICT total exports. Even large countries like France and Germany were not specialised in ICT as a whole. During the 1990s this pattern changed somewhat, to include the small countries Sweden, the Netherlands and Finland. In the Swedish and Finnish cases two ICT companies, Ericsson and Nokia, were the major forces behind this pattern (particularly with production of mobile communications equipment). Exports from the Netherlands were specialised in several sub-groups , such as, electro medical, computers, electronics and office machinery. For the Dutch pattern this can be related directly to Philips in terms of non-Dutch production (and thus exports) of consumer electronics and lack of success in telecommunications hardware. The lack of Danish specialisation in ICT hardware at the aggregate level is striking. A more fine-grained analysis may, however, modify this picture slightly. Table II shows that Denmark was specialised in telecommunications equipment in 1998. Electro-medical equipment is the only segment of electronics in which Denmark has been specialised since the early 1960s (Dalum et al., 1988).

"Take in Table II"

Although it should be borne in mind that these results are sensitive to the methods used, such as level of aggregation and choice of years, national export specialisation patterns are generally fairly stable or 'sticky' over time (Dalum et al., 1998). The main feature of Danish telecommunications in the 1990s is that it was below one apart from 1990 and 1998. However, further disaggregation of the data may reveal segments where some of the countries happened to be specialised. Table III presents

export data for the large and rapidly growing mobile communications equipment segment. In this segment Denmark has persistently been specialised in the 1990s, while France and Germany entered a phase of specialisation only in the late 1990s. But this pattern has changed more recently; mobile phones have not been manufactured in Denmark since 2004.

"Take in Table III"

From this international comparison of the manufacturing segment of ICT it cannot be concluded that the relative weakness of Denmark is an isolated phenomenon in the EU. It also applies to such diverse countries as Germany (except for instruments), France, Italy, and Greece. The cases of Sweden, Finland and the Netherlands illustrate that small country size is not an inhibiting factor in itself. What is important appears to be whether historical evolution of their respective national systems of innovation has led to the formation of large 'domestic' multinationals of the Ericsson-Nokia-Philips type. This was evidently not the case in Denmark.

Denmark has generally been characterised by a structure of small and medium sized ICT firms, as discussed in Dalum et al. (1988). In the mid-late 19th century and the early decades of the 20th century the Great Northern Telegraph Company was a large international player in telegraph technology, which might have become an embryo 'Danish Ericsson'. However, Great Northern never managed to enter telephone technology with the thrust that characterised Ericsson in Sweden and Siemens in Germany. In the early post World War II period Great Northern entered the emerging radio communications field through the acquisition of a small start-up, which was named Storno. This sector became the stronghold in Europe of Ericsson and Storno alongside Motorola and General Electric in the U.S. In the 1950s and 1960s Storno was the third largest producer world-wide, next to these two U.S. companies. Storno produced what is today known as 'closed' radio communications systems for police forces, airports, transport companies, etc. Storno and Ericsson were heavily involved in developing the path breaking Nordic Mobile Telephony (NMT) system launched in 1981

as the worlds first cross international public (or 'open') mobile communications system, a predecessor of the successful GSM system. While the early 1980s witnessed phenomenal growth of Nokia in Finland, originally based on mobile phone terminals, and later on entire systems, a 'counterfactual' discussion has been ongoing in Denmark about whether or not, at a certain stage, a 'Danish Nokia' had been a real option.

There do not seem to be any 'basic laws' of economics that prevented another path of development for the Danish telecommunications industry. Although small, Storno was a world leading company, and a distinct research tradition in the wireless field had already emerged at the Danish Technical University in Copenhagen in the early decades of the 20th century. The Great Northern group sold Storno to General Electric (US) in 1976, and the company was passed on to Motorola in 1986. Great Northern, like many other companies, could not in 1976 see the enormous market potential of mobile telephony. If it had the Danish ICT manufacturing landscape would have looked significantly different. Motorola used Storno as an entry port in order to become a more central player in the early stages of the GSM standardisation process, responsibility for which was assumed by a new European body, the European Telecommunications Standards Institute, ETSI, in 1987. To become a player in the ETSI context required a presence in Europe. As Motorola's European development arm, Storno managed to develop a GSM terminal in 1992 in line with Ericsson, Nokia and the north Denmark DC Development, a joint venture between two domestic mobile phone producers in the Aalborg region.

Of the first four GSM phones two were developed in Denmark, one in Sweden and one in Finland. Motorola subsequently moved its GSM development activities to the US. The two Aalborg firms were financially drained by the development effort, preventing them from entering a growth process of Ericsson-Nokia dimensions. However, mobile phone equipment continued to be an area of specialisation in Denmark until recently. The patterns for Sweden and Finland in the 1990s are remarkable, and Germany (Siemens) and France (Alcatel) have also become specialised. The US, in spite of being home to one of the top three mobile phone producers, Motorola, had experienced a decreasing specialisation in mobile phones in the last half of the period. The lack of a common US

standard for second generation (2G) mobile phone technology compared to European and Asian scene appears to be an important part of the explanation of this pattern.

In addition to mobile communications Denmark has been specialised in the electro-medical equipment field, dominated by small and medium sized enterprises (SMEs), who have developed highly specialised niche products, often through intense collaboration with hospital doctors. The most important knowledge flows for these niche firms have generally been a combination of strong interaction with the users in the innovation process and strong links with university research.

While the trade data for ICT hardware can be used as a reasonable structural indicator in an international context, it is much more difficult to make international comparisons for the ICT service industries. During the 1980s and 1990s standardised - and machine independent - packages of software became very widespread. The US has generally dominated this market through such companies as Microsoft, Lotus, SAS, SPSS and Oracle. At the less standardised end of the market US companies such as EDS, Computer Associates and the omnipresent IBM have dominated the ICT services market through semi-standardised software packages, which have then undergone extensive modification by each company.

ICT services and consulting has been domestically oriented in most countries. Although software packages (and hardware) have become standardised, implementation and modification of large ICT service systems continued to be a rather customised business activity well into the 1990s. Packages such as Oracle and the German SAP have emerged as more standardised solutions for larger firms.

In the 1980s ICT services and consulting in most countries consisted of two main segments in. Mainframe-based service suppliers comprised a mix of affiliates of large US hardware companies (especially IBM) and US software companies (such as EDS) and national consultancy companies. In the Danish case, the latter segment was composed either of large domestic companies (such as Mærsk Data, ØK Data and LEC) or banks (PBS, Bankdata, SDC) and government organisations (Kommunedata and Datacentralen). Following the emergence of microcomputers an entire segment of PC distributors evolved.

Due to the typically rather centralised administrative procedures of government in Denmark, the mainframe-based service suppliers (whether private or government owned) tended to be dominant in the 1980s. During the 1990s application of first stand-alone PCs and then PC networks and the Internet naturally caused turbulence in ICT services and consulting, although the overheated and dramatic rise and fall of the 'dotcom' segment did not become very prolific in Denmark, as it – temporarily - did in Sweden. The government-owned Kommunedata and Datacentralen were privatised at the end of the 1990s. Kommunedata (IT solutions for the municipal administrations), now named KMD, underwent privatisation but without being changed fundamentally. Datacentralen was sold to CSC (the large US IT consultancy company). These two companies are quite big, even in an international context, but very much oriented towards the domestic market.

A small segment of developing software applications emerged in the 1990s. Two firms, Navision and Damgaard Data, managed to develop total IT solutions for SMEs in terms of standardised packaged software with a certain international market presence. These two firms merged to become Navision-Damgaard, which became internationally known and was subsequently acquired by Microsoft, who wanted to enter this segment.

The mainframe-based IT service firms experienced tremendous pressure during this period from PCs and network distributors. During the 1990s solutions based on PCs connected in networks, were substituted for mainframe based solutions. However, by the end of the 1990s and at the beginning of the 2000s, these two groups of actors increasingly converged. A trend towards IT solutions based on PCs in networks, with a centralised structure for servers and software, has changed the direction of development once again. Due to the heavy financial pressure on the sector from the beginning of 2000, substantial restructuring took place and this is still ongoing. The trend would appear to be towards a small group of firms capable of delivering, and even managing, total IT solutions for private firms as well as government authorities. The firms in the segment have been converging with the old mainframe-based IT consultants to become a group of 'complete service and network suppliers'. Many of these firms, which all grew out of distribution of PCs and standardised (US) software packages, have experienced severe economic problems and some have filed for bankruptcy. The

dotcom segment has been shrinking rapidly due to the crisis in the IT sector and the cut in IT spending.

The structural change is still ongoing as one of the largest Danish owned IT service companies Mærsk Data (some years before merged with another company under the name DM Data) was taken over by IBM in late 2004. Without reservation it can be concluded that the Danish IT service and consulting segment is not a major international player. And there are no signs that this may be the case in the foreseeable future. This would hold even if the telecommunications service segment was included as assumed by the term ICT services. The telecom service sector accounts for 16% of total ICT employment in Denmark (Table I), but is rather domestically oriented. The mobile communications segment has similar characteristics. The biggest company is TDC, followed by Sonofon, owned by Norwegian Telenor. The mobile service providers are technically fairly advanced in an international context, but they are not large companies.

To summarise: The general impression of an internationally rather weak Danish ICT sector appears well founded.

4 Education and R&D related to the Danish ICT sector

The previous Section 3 pointed at the lack of large firms in the ICT sector as an important feature behind the relative weak international competitiveness of the sector. As mentioned in the Introduction, a substantial amount of data on the use of ICT equipment and services indicate that the markets of the small rich countries - as well as the US market - represent the most advanced demand. This is typically illustrated by per capita penetration ratios in such fields as broadband Internet connections, mobile phones, PCs in homes, etc. (see, for example, OECD, (1999; 2000b, appendix tables 4-6)). There is no reason to believe that the quality of the Danish demand for ICT equipment and services should be of low quality. On the contrary, available indicators point in the opposite direction. The possible further explanations may apparently have to be found on the labour supply side.

The Danish higher education system and especially the system for vocational training of skilled workers, is generally considered to be of a high standard.

The high numbers of university educated employees in the Nordic ICT industries are striking, see Table IV. The close similarities in their education systems are probably the reason for this. However, Table IV shows that Denmark is systematically ranked below its fellow Nordic countries. Finland has by far the largest proportion of higher educated employees in ICT among these four countries. The relative small, and internationally weak, ICT sector in Denmark may to some extent be explained by the small numbers of engineers and computer scientists being produced.

"Take in Table IV"

There are two technical universities in Denmark producing engineers in electronics at the bachelor (diploma engineers), masters and PhD levels: the Technical University in Copenhagen (DTU) and Aalborg University (AAU). DTU has been internationally known in electrical engineering for two centuries. AAU, founded in 1974, became quickly established in electronics, and was responsible for educating half of the Danish masters' students in electronics from the early 1990s. There is also a system of decentralised engineering schools, providing bachelors training in electrical engineering, which were originally set up to offer a higher education opportunity for skilled workers to follow a tailor made admissions programme. There are six such schools. Computer scientists are trained at the Copenhagen, Aarhus and Aalborg universities, and the Universities of Southern Denmark and Aarhus have recently started small programmes in electrical engineering. The country appears to be well equipped with institutions capable of educating the relevant manpower. The problem is that too few students want to take these degrees - in spite of increased job opportunities in the second half of the 1990s and again more recently in the 2000s. A phenomenon experienced in other western European countries as well in this period.

The relative distribution of R&D expenditure within manufacturing industries is shown in Table V for a group of small advanced OECD countries, as well as for the entire OECD. The data also include a comparison according to four levels of R&D intensity.

"Take in Table V"

The Danish (and Dutch) emphasis on food processing related R&D is outstanding with a share three times as large as the OECD average of 2%. The relative specialisation in pharmaceuticals R&D is also approximately 3, but this represents 30% of Danish R&D expenditure in manufacturing. Conversely, Danish R&D efforts in ICT manufacturing are generally very small in an international context. A more direct indicator is the OECD measure of ICT research in total business enterprise expenditure on R&D (OECD, 2000b, Table 14). Denmark lagged behind the 14 most developed OECD countries in 1997 with a share of 7.2% and was also at the lower end in terms of business sector share of R&D for communications services (telecom services).

The high degree of concentration of R&D expenditure on a few industries for the small high-income OECD countries shown in Table V is quite clear. In Finland the increase in specialisation from 1.3 to 3.1 in telecommunications equipment & semiconductors reflects that this industry accounted for 50% of Finnish manufacturing R&D in 1998, basically due to the very rapid growth of Nokia. For Sweden, the dominance of Ericsson is less outstanding, although this industry contributes with more than 20% of Swedish manufacturing R&D.

5 3G, fiber to the home and next generation wireless communication standards in Denmark

In the mobile communications field the Nordic countries have gained the reputation of being among the world-wide leaders. At the company side this applies for Sweden and Finland and previously to some extent for Denmark, but not for Norway (and Iceland). Mobile communications

represents a now classic case of close interaction between advanced demand characteristics, institutional set up, public regulation and international competitiveness of the supplier industries - that is, the very essence of the factors emphasised in the user-producer interaction school of thought in innovation theory.

The establishment of the Nordic Mobile Telephony System (NMT) in 1981, through cooperation between the Nordic telecom service providers and the regulatory authorities, created the first ever cross-border market for public mobile telephony, based on a common standard. This was decisive for the Nordic firms (Ericsson, Nokia and the US-Danish Storno) becoming world leaders in mobile communications equipment from the early 1980s. This strong competitive position was strengthened further when the pan-European GSM standard, now the dominant world 2G standard, was implemented in 1992. In the late 1980s the Nordic companies and authorities, with Nokia and Ericsson acting as the leading architects to a substantial degree, influenced the GSM standardisation process. The largest producer of mobile terminals at the time, Motorola, acquired Storno in Denmark in 1986 to avoid being excluded from this important process.

The story has to a large extent been repeated in the 1997-98 specifications for the third generation (3G) mobile communications system, Universal Mobile Telecommunication System (UMTS), which also was dominated by Ericsson and Nokia. The development of the mobile communications industry is probably one of the most clear 'textbook' examples of the role of advanced users and a well adapted institutional context. Previously, the Nordic countries were the 'lead-users'. However, this will not necessarily will be the case in the future. The allocation of UMTS licences in Europe in 2000 was very turbulent, resulting in skyrocketing costs for the telecom operators to become licence holders. The ensuing financial crisis in the telecommunication services sector, accompanied by large scale redundancies and reduced expectations for diffusion of 3G systems has marred the introduction of 3G in Europe. The massive investments required to build the infrastructure combined with the deep financial problems of the telecommunications sector in general (the equipment industry as well as telecommunications services) have caused the establishment of 3G networks to be delayed all over Europe. Nevertheless, in spite of these problems 3G services have been introduced in several

European countries - in Denmark in October 2003. But it appears so far that the previous Nordic/European advantage of being early advanced users has been lost.

The growth of 3G services in Denmark has been slow, but after successive price cuts it has got a foothold and the number of users is increasing. In early 2005 the number of subscribers reached 125,000, still a rather small number compared to the 5 million GSM subscribers. There are four 3G licences in Denmark, but the new entrant Hi3G Mobile (now called '3') is still the only operator offering services. These other license holders are building their networks according to the license agreements, but their strategy seems to be to await the development in the rest of Europe and let 3 in Denmark have a hard time introducing 3G. Meanwhile they continue with incremental improvements of their GSM networks to GPRS and EDGE. This strategy affects the investments in ICT infrastructure, which tripled from 1995 to 2001, halved from 2001 to 2003, but took off again in 2004 (Ministry of Research and Information Technology, 2005).[2]

In 2004 the manufacturing of mobile phone terminals almost disappeared with the closing of the Flextronics plant in North Jutland. In the 1980s Denmark was represented by Storno (Motorola from 1986), Dancall and Cetelco in the mobile phones industry; Storno was located in Copenhagen while the two latter were located in the mobile communications cluster around Aalborg in North Jutland (see Dalum et al. 2005). In the first half of the 1990s Motorola stopped production in Denmark and production at Cetelco was closed down in the mid 1990s. Dancall became financially drained in 1992, but was taken over by Amstrad (UK) and subsequently by Bosch who invested in a major manufacturing plant in the Aalborg region. At the end of the 1990s Bosch withdrew from the industry and sold the manufacturing activities to Flextronics while Siemens Mobile Phones took over the R&D department of 350 persons. In the early 2000s Flextronics was the only remaining producer of GSM terminals with a fairly high annual production; but this plant was closed at the end of 2004.

What remains of this segment is a fairly broad set of companies developing mobile communications equipment for 2G and 3G. The Aalborg cluster, called NorCOM[3], contains close to 40-50 firms in radiocommunications technologies, of which many are development laboratories owned by foreign

companies, such as Siemens Mobile Phones (in summer 2005 taken over by BenQ from Taiwan), Texas Instruments, Analog Devices, Infineon, Nokia, RF Micro Devices, Freescale (Motorola), Rohde & Schwarz, TTPCom and Cambridge Silicon Radio. In the Copenhagen region Nokia is dominant with a major development centre with more than 1200 employees. In another segment Thrane & Thrane is an internationally leading producer of satellite communications equipment.

In general it can be stated that Denmark has lost its position with internationally visible, albeit not large, production activities of GSM terminals. However, within the NorCOM cluster in North Jutland and, not to forget, Nokia in Copenhagen a broad set of development activities, mainly foreign owned, play a pretty active role on the international scene. But it seems fair to conclude so far that the rather prolific role of Danish development activities in 2G equipment appears to become less prominent in 3G activities.

At the university side there has been ongoing research in the optical communications field at DTU in Copenhagen at the COM Centre while wireless research has been concentrated at AAU in Aalborg, from 1992 at the Centre for Personal Communications (CPK). During the 1980s and 90s university research as well as private sector production and development activities have been quite outspoken in the Copenhagen region, but the private sector activities were hit significantly when the IT bubble burst in 2000 and onwards.[4] At AAU the CPK centre has been renewed and enlarged in terms of the Centre for TeleInFrastructure (CTIF) launched in 2004. It contains the coordinating group for a major next generation wireless technology EU 6th Framework project, MAGNET, various industry sponsored research projects (by e.g. Samsung, Nokia and NTTDoCoMo) as well as several other international projects supported by EU funds and national research projects. CTIF comprises more than 120 researchers and has been established as a major centre for research in 4G technologies with a deliberate focus on future convergence between wired and wireless technologies.

One of the major driving forces behind the introduction of 3G has been the (probably unlimited) demand for data access on the move. The first wave of 3G systems in operation have by no means been able to satisfy this demand. The existing 3G systems are, so far, characterized by rather poor data

transmission characteristics. When the presently announced systems are rolled out at a larger scale during the next 2-3 years in several European countries transmission speed will - at the present technological performance - at best be of a magnitude of a few hundreds Kb/s. When diffused at a larger scale 3G systems will no doubt represent a superior mobile telephony technology compared to the present 2G systems, but 3G has been vastly oversold as an omnipotent solution to most kind of needs within data communication. Several European operators have paid huge sums of money for acquiring the required spectrum licenses.[5] The major operators have been somehow caught in a trap where they are locked-in to the roll out of their 3G systems.[6]

However, there are other technologies capable to deliver wireless access to the Internet, such as WLAN (IEEE 802.11) and WiMAX (IEEE 802.16). These technologies are on the one hand disruptive, but on the other they are also complementary. The massive investments required to build the 3G infrastructure paired with financial problems of the telecommunications sector in general has increased the focus on what is coming next in the horizon. 4G has loosely been defined as the complete integration between the wired and the wireless spheres of telecommunications with speeds of data communications of 100-150 Mb/s. There is a certain amount of ambivalence prevalent in the terminology at present, but the convergence between the wired and wireless seems to be central in the framework for 4G. However, to obtain high speed and personal adaptive network solutions the quality of the underlying wired infrastructure is central (Dalum et al., 2005). There are many potential alternatives to a wireless infrastructure mainly based on 3G networks. In the short run it would be technically possible to build on combinations of the following three elements: (1) continue the present upgrading of the 2G networks to EDGE ('2,75G'), (2) speed up the transmission from copper cables to optical fibres in the 'fixed' or wired networks and (3) establish a structure of wireless access points of the WLAN type. Such combinations could – in the right mix – probably deliver significantly more consumer satisfaction than early-stage under performing 3G networks and terminals.

There are, not surprisingly, vested interests involved in this game. The large operators have invested heavily in getting the 3G licences as well as in rolling out the network infrastructure. Given the focus on the Nordic countries in the present special issue, there are some obvious structural

differences at hand. In Sweden and Finland, two very large international players in the equipment industry, Ericsson and Nokia, represent interests in getting the 3G systems rolled out successfully, given that they are two of the world dominant infrastructure vendors. In Denmark, on the other hand, there is not such a strong equipment segment, which potentially could make launch of experiments with alternative infrastructure solutions more easy.

Such experiments have been proposed already in 2002 by the founding fathers of the CTIF research centre in Aalborg and the local ICT industry. These proposals have been based on very detailed plans for a Fiber To The Home solution for the entire North Jutland county. Wireless Internet access should bee build as an ad-on in such a context. These ideas have meet heavy opposition from another kind of vested interest, i.e. the incumbent dominant telecom operator, TDC (the previous government owned monopoly operator), which owns the last mile 'raw copper', as a result of the 'deregulation' set-up in Denmark established in 1996.

During the last couple of years the diffusion of Internet connections has been very fast in Denmark. Especially the number of Asymmetric Digital Subscriber Line (ADSL) connections has grown from 26,000 in ultimo 2000 to 562,000 in medio 2004 (www.itst.dk). In international comparisons of penetration and availability ratios, Denmark is now usually found among the best in Europe. ADSL connections are available in all Danish municipalities, and available to 96% of all households and firms (Ministry of Research and Information Technology, 2004). The numbers indicate that Denmark is doing well in respect to ICT infrastructure, but this is only a partially correct picture, since the existing infrastructure is based on the old telephone network that is insufficient for the future demand. The incumbent operator decides when the market will be allowed to get a more upgraded infrastructure and/or establish major field experiments with alternative solutions. TDC has been privatised and acts, to no surprise, accordingly – i.e. it appears to be rational to stick to the existing copper wired infrastructure, gradually improve the speed on this and roll out a 3G network profitably. In this context major field experiments with the infrastructure may often turn out not to be rational.

Recently, several new actors have entered or are planning to enter the market for ICT infrastructure by building their own regional optical fiber to the home (FTTH) networks. Especially the Danish power suppliers have been very interested. They want to expand their business, and are in a process of converting their overhead power lines to power lines in the ground, i.e. they could save money on digging costs. The digging costs is the most expensive part of building ICT infrastructure. They are planning to build FTTH networks to their customers. In North Western Zealand, the power supplier has begun offering optical fiber connections direct to the home to its customers. The power supplier in the southern part of North Jutland (Himmerlands Elforsyning) has started to build a fiber network to all their customers to be finished within 5-10 years. Other power suppliers, energy companies, user associations, and (semi) public organisations etc. are also planning fiber networks, or building networks in limited test areas[7]. The incumbent operator, TDC, is planning optical fiber Internet connections - as a counterattack - to the Funen county, but only in the densely populated areas and apparently at a higher price for the consumers.

These FTTH initiatives are emerging all over the country and are causing a major battle involving TDC, the power suppliers, many kind of user interests and the political level. This turbulent situation could potentially open the field for fertile experiments, which could position Denmark as an advanced user in the ICT infrastructure field and create new opportunities, which could revitalise Danish companies as early producers of the required solutions. At present there is no clear indication of where this battle may end. The wired ICT infrastructure issue is very open ended in Denmark as is, logically, the outlook for wireless access to the networks.

6 Conclusion

The mobile communications field in the Nordic countries represents a now classic case of close interaction between advanced demand characteristics, institutional set up, regulation and international competitiveness of the supplier industries.

This has been important background for the outstanding success of the Swedish and Finnish telecom equipment industry in recent decades. Denmark has been lacking behind on the supply side, basically reflecting a 'lack-of-Ericsson-Nokia' effect. The absence of a large scale player appears to be the main factor behind the decreasing strength of the Danish industry in this ICT segment, where a series of other prerequisites have been available, as in Finland and Sweden. To go deeper in the explanation of why such a leading player did not emerge would require a detailed study of the development of the most obvious candidate, Storno, as well as the less obvious candidate, Dancall. This is, however, outside the scope of the present paper.

For the remaining part of the Danish ICT sector it has also been a common feature that no big international players have emerged. But here there has not even been obvious candidates, although there exist leading firms within various narrow niches in instruments and electro-medical equipment, such as Radiometer in Copenhagen, or Bang & Olufsen in design intensive consumer electronics in Jutland. There has, however, been several examples of small 'high fliers' with very advanced solutions, that have been acquired by the large international players at an early stage. Among the outstanding examples have been Intel's takeover of Giga in Copenhagen in the field of semiconductors for the optical communications equipment; Ericsson's takeover over Telebit in Aarhus in Internet equipment; Microsoft's takeover of Navision in the field of integrated IT management solutions for SMEs; Cisco's recent takeover of Kiss Technology north of Copenhagen in the field of DVD equipment approaching the TV world 'from the computer side'. Given the relative high quality of the engineering education system and the university R&D system it has apparently become the 'fate' of the Danish ICT sector to become advanced subcontractor of small high technology firms to be taken over by the large multinationals.

The net effect has been that the ICT sector *per se* never has entered a large scale growth phase nor fostered big international players. There are several advanced small and medium sized companies within the sector, but there is not indication at present that the sector will grow big. The mismatch can be stated as plenty of advanced demand, but far too few suppliers. Among these, there have, however,

been several advanced companies, but their destiny have historically been to become swallowed by the large foreign multinational companies, with only a few notable exceptions.[8]

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7 Appendix

"Take in Table VI"

Table I Employment and exports for the Danish ICT sector, 1997

Segment	Number of full time employees	Share of ICT employment	Share of total Danish employment	Exports (DKK 1,000)	Share of ICT Exports	Share of total Danish Exports
Manufacturing						
Computers	2,725	3%	0.24%	1,007,853	3%	0.24%
Communication equipment	11,213	12%	1.01%	1,458,853	4%	0.34%
Instruments	5,420	6%	0.49%	3,252,103	10%	0.76%
Total ICT manufacturing	19,358	21%	1.74%	5,718,809	18%	1.34%
Services						
Wholesale	38,869	41%	3.49%	21,760,539	67%	5.09%
Telecommunications services	15,242	16%	1.37%	1,596,634	5%	0.37%
IT services and consulting	20,280	22%	1.82%	3,457,074	11%	0.81%
Total ICT services	74,391	79%	6.68%	26,814,247	82%	6.27%
Total ICT sector	93,749	100%	8.42%	32,533,056	100%	7.60%

Note: Definition of the segments is shown in the appendix.
Source: Based on data from Statistics Denmark.

Table II Export specialisation in ICT and electro medical products, 1990-1998.

	Germany									**Denmark**								
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1990	1991	1992	1993	1994	1995	1996	1997	1998
Electro medical	0.73	0.71	0.87	0.89	0.93	0.96	0.95	0.90	**1.06**	**2.20**	**1.90**	**1.82**	**1.74**	**1.81**	**1.87**	**1.68**	**2.06**	**1.70**
Telecom. equipment	0.74	0.83	0.83	0.84	0.86	0.81	0.78	0.81	0.70	**1.16**	0.93	0.95	0.78	0.79	0.72	0.83	0.95	**1.14**
Consumer	0.54	0.47	0.38	0.32	0.32	0.31	0.34	0.28	0.26	0.76	0.72	0.69	0.50	0.56	0.72	0.74	0.76	0.78
Computers	0.64	0.64	0.59	0.57	0.53	0.52	0.49	0.50	0.53	0.42	0.51	0.50	0.49	0.59	0.48	0.48	0.47	0.41
Electronic	0.59	0.63	0.57	0.55	0.60	0.63	0.61	0.63	0.59	0.16	0.15	0.15	0.20	0.18	0.16	0.17	0.20	0.21
Office machinery	0.55	0.47	0.51	0.44	0.45	0.50	0.50	0.46	0.46	0.42	0.21	0.19	0.22	0.20	0.21	0.17	0.19	0.15
Instruments etc.	**1.19**	**1.16**	**1.26**	**1.24**	**1.18**	**1.17**	**1.20**	**1.11**	**1.14**	**1.07**	0.96	0.98	0.98	0.98	0.94	0.85	0.89	0.94
ICT total	0.68	0.68	0.65	0.62	0.62	0.62	0.61	0.61	0.60	0.57	0.54	0.54	0.49	0.53	0.51	0.52	0.56	0.58
	Finland									**France**								
Electro medical	**1.57**	**1.91**	**1.93**	**1.96**	**2.08**	**1.93**	**2.35**	**2.73**	**2.46**	0.41	0.42	0.35	0.34	0.37	0.32	0.33	0.37	0.28
Telecom. equipment	**2.38**	**1.72**	**2.16**	**2.80**	**3.31**	**4.10**	**4.06**	**4.01**	**4.99**	0.94	0.93	0.84	0.80	0.76	0.80	0.81	0.92	**1.07**
Consumer	0.54	0.45	0.34	0.36	0.33	0.30	0.27	0.32	0.33	0.42	0.43	0.39	0.35	0.33	0.36	0.37	0.37	0.43
Computers	0.39	0.46	0.74	0.78	0.77	0.64	0.60	0.65	0.55	0.76	0.80	0.81	0.72	0.68	0.68	0.76	0.78	0.77
Electronic	0.26	0.24	0.25	0.24	0.26	0.23	0.26	0.29	0.37	0.56	0.54	0.54	0.61	0.63	0.74	0.83	0.85	0.81
Office machinery	0.05	0.07	0.07	0.11	0.13	0.09	0.11	0.11	0.16	0.54	0.60	0.59	0.57	0.55	0.64	0.68	0.61	0.50
Instruments etc.	0.74	0.76	0.69	0.68	0.63	0.64	0.58	0.65	0.65	0.77	0.74	0.72	0.71	0.67	0.69	0.69	0.70	0.64
ICT total	0.66	0.57	0.70	0.81	0.90	**1.00**	0.99	**1.06**	**1.24**	0.67	0.67	0.65	0.63	0.62	0.67	0.72	0.75	0.77
	United Kingdom									**Sweden**								
Electro medical	0.72	0.62	0.69	0.47	0.42	0.43	0.40	0.41	0.41	0.69	0.58	0.59	0.63	0.49	0.66	0.51	0.46	0.98
Telecom. equipment	**1.09**	**1.07**	**1.05**	0.85	**1.02**	**1.22**	**1.39**	**1.39**	**1.57**	**3.08**	**3.15**	**3.12**	**3.48**	**3.75**	**4.23**	**5.12**	**5.39**	**5.21**
Consumer	0.70	0.77	0.61	0.61	0.68	0.71	0.81	0.72	0.67	0.16	0.14	0.12	0.12	0.16	0.18	0.19	0.17	0.28
Computers	**1.61**	**1.64**	**1.62**	**1.73**	**1.71**	**1.77**	**1.63**	**1.63**	**1.60**	0.70	0.66	0.59	0.39	0.28	0.23	0.23	0.21	0.20
Electronic	0.61	0.57	0.62	0.95	**1.02**	**1.15**	**1.06**	0.85	0.82	0.33	0.29	0.30	0.31	0.34	0.33	0.50	0.48	0.43
Office machinery	0.78	0.74	0.74	0.54	0.63	0.65	0.79	0.85	0.76	0.27	0.25	0.22	0.21	0.21	0.24	0.26	0.21	0.21
Instruments etc.	**1.49**	**1.44**	**1.37**	**1.32**	**1.32**	**1.34**	**1.35**	**1.43**	**1.40**	0.99	**1.05**	**1.02**	**1.00**	0.97	0.98	0.89	0.79	0.78
ICT total	**1.09**	**1.08**	**1.04**	**1.12**	**1.18**	**1.29**	**1.28**	**1.22**	**1.23**	0.83	0.82	0.80	0.80	0.85	0.93	**1.11**	**1.20**	**1.19**
	USA									**Netherlands**								
Electro medical	**3.37**	**3.30**	**3.38**	**3.43**	**3.51**	**3.60**	**3.68**	**3.50**	**3.37**	0.58	0.82	0.77	0.77	**1.00**	**1.30**	**1.21**	**1.35**	**1.32**
Telecom. equipment	**1.40**	**1.39**	**1.41**	**1.49**	**1.47**	**1.46**	**1.30**	**1.26**	**1.19**	0.73	0.66	0.64	0.59	0.50	0.52	0.53	0.40	0.34
Consumer	0.37	0.35	0.35	0.33	0.36	0.35	0.38	0.38	0.40	0.44	0.40	0.39	0.39	0.37	0.40	0.52	0.47	0.47
Computers	**1.96**	**1.91**	**1.92**	**1.71**	**1.64**	**1.56**	**1.60**	**1.54**	**1.52**	**1.33**	**1.18**	**1.24**	**1.41**	**1.41**	**1.46**	**1.94**	**2.19**	**2.60**
Electronic	**1.38**	**1.25**	**1.27**	**1.32**	**1.48**	**1.62**	**1.66**	**1.71**	**1.84**	0.43	0.42	0.44	0.75	0.73	0.80	0.91	**1.04**	**1.04**
Office machinery	0.62	0.63	0.64	0.56	0.51	0.52	0.62	0.64	0.88	**2.27**	**2.27**	**2.40**	**2.25**	**2.72**	**2.73**	**2.75**	**2.85**	**2.73**
Instruments etc.	**1.55**	**1.58**	**1.56**	**1.57**	**1.56**	**1.55**	**1.55**	**1.57**	**1.58**	0.53	0.57	0.61	0.58	0.57	0.55	0.61	0.64	0.70
ICT total	**1.37**	**1.32**	**1.31**	**1.28**	**1.31**	**1.34**	**1.35**	**1.34**	**1.39**	0.85	0.79	0.81	0.91	0.91	0.95	**1.15**	**1.23**	**1.35**

Note: Electro medical is not included in the ICT total. Instruments etc. are instruments and equipment for detecting, measuring, checking and controlling physical phenomena or processes.

Source: Based on data from OECD (2000) *International Trade by Commodities Statistics, No. 1*.

Table III Export specialisation in mobile phones, 1990-1998.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Denmark	**3.38**	**2.02**	**1.99**	**1.87**	**1.30**	**1.07**	**1.29**	**1.59**	**2.02**
Finland	**4.55**	**4.69**	**7.90**	**8.95**	**8.68**	**9.50**	**9.59**	**8.20**	**9.72**
France	0.62	0.67	0.35	0.53	0.48	0.65	0.85	**1.11**	**1.24**
Germany	0.68	0.64	0.55	0.60	0.95	**1.08**	**1.11**	**1.21**	**1.00**
Greece	0.03	0.05	0.03	0.05	0.11	0.11	0.19	0.26	0.48
Italy	0.57	0.67	0.65	0.49	0.25	0.27	0.20	0.19	0.20
Netherlands	0.08	0.06	0.09	0.11	0.10	0.11	0.08	0.11	0.08
Sweden	**3.83**	**4.45**	**4.96**	**6.17**	**6.08**	**7.23**	**7.75**	**8.05**	**7.50**
United Kingdom	**1.82**	**2.10**	**1.71**	0.90	**1.30**	**1.26**	**1.84**	**1.67**	**2.11**
USA	**1.99**	**2.07**	**2.36**	**2.45**	**2.00**	**1.68**	**1.26**	**1.16**	0.95

Note: Mobile phones are defined as SITC Rev. 3 code 764.32. The specialisation index is based on OECD (23).
Source: Based on data from OECD (2000) *International Trade by Commodities Statistics, No. 1*.

Table IV Percentage of employees in ICT with tertiary education[1], 1998.

	Denmark[2]			Norway[3]			Finland	Sweden
	Non-university tertiary	University-level tertiary	Total tertiary	Non-university tertiary	University-level tertiary	Total tertiary	Non-university and university tertiary	Non-university and university tertiary
ICT manufacturing	8	17	25	14	24	38	45	37
ICT services	7	20	27	19	24	43	52	47
Wholesale of ICT products	8	16	24	16	13	29	51	35
Telecommunications	4	13	17	19	21	40	44	28
ICT Services and Consultancy	6	31	37	22	35	57	59	62
Total manufacturing[4]	5	8	13	7	7	14	24	18
Total services Activities[5]	4	11	15	12	11	23	31	24
Total private sector[6]	4	9	13	10	9	19	28	21

[1] Tertiary education is equal to ISCED level 5 (Non-university tertiary education) and ISCED Level 6 and 7 (University-level tertiary education). [2] 1996 level. [3] 1999 level. [4]Total manufacturing (NACE 15-37). [5] Total services activities (NACE 50-74, 92). [6] Total private sector (NACE 15-37, 45, 50-74, 92, 93).
Source: Based on Nordic Statistical Institutes (1998) and Nordic Statistical Institutes (2000).

Table V R&D specialisation in manufacturing for selected small OECD countries

	OECD-14[1]		Denmark[2]		Sweden		Netherlands		Finland	
	1990	1995	1990	1998	1990	1995	1990	1996	1990	1998
Food, beverages, tobacco	2.0	2.0	3.5	3.1	1.0	0.7	2.9	3.7	3.4	1.2
Textiles and clothing	0.6	0.6	1.0	0.2	0.6	0.4	0.8	0.8	1.6	1.2
Wood and furniture	0.2	0.4	1.8	0.8	0.5	1.0	0.0	1.4	5.1	2.3
Paper and printing	11.5	1.3	0.5	0.3	3.6	2.4	0.4	0.6	8.7	3.2
Chemicals	21.2	21.6	1.4	1.6	0.9	0.9	1.8	1.5	1.0	0.6
Pharmaceuticals	*7.6*	*9.6*	*3.1*	*3.1*	*1.8*	*1.7*	*1.1*	*1.2*	*0.7*	*0.4*
Non-metal mineral products	1.2	1.1	1.8	0.7	0.5	0.5	0.3	0.5	1.8	0.9
Basic metals	2.1	1.8	0.7	0.3	1.0	0.8	0.7	1.2	1.7	0.8
Metals and machinery[3]	71.1	70.7	0.7	0.7	1.0	1.0	0.7	0.8	0.8	1.1
Non-electrical mach.	*6.0*	*7.1*	*2.6*	*3.2*	*2.3*	*1.7*	*0.5*	*0.5*	*2.3*	*1.7*
Computers	***9.8***	***7.1***	***0.3***	***0.2***	***0.3***	***0.2***	***0.4***	***0.7***	***0.3***	***0.1***
Telecom & semiconductors	***14.5***	***16.3***	***0.7***	***0.6***	***1.9***	***1.4***	***1.1***	***0.9***	***1.3***	***3.1***
Shipbuilding	*0.1*	*0.2*	*21.5*	*13.0*	*2.9*	*0.5*	*1.0*	*1.1*	*10.2*	*1.4*
Motor vehicles	*12.6*	*14.4*	*0.0*	*0.0*	*1.3*	*1.3*	*0.4*	*0.5*	*0.1*	*0.0*
Aerospace	*14.4*	*10.7*	*0.0*	*0.0*	*0.4*	*0.5*	*0.1*	*0.2*	*0.0*	*0.0*
Scientific instruments	*4.9*	*7.3*	*2.4*	*1.2*	*0.2*	*1.1*	*0.2*	*0.2*	*1.1*	*0.6*
Other manufacturing	0.6	0.6	14.4	12.1	0.4	0.2	0.0	0.2	0.8	1.0
Total manufacturing	100.0	100.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High-tech industries	46.5	43.8	0.8	0.9	1.1	1.1	0.7	0.8	0.6	1.3
Medium-high technology	40.7	44.1	0.9	0.9	1.0	1.0	1.4	1.1	1.0	0.6
Medium-low technology	9.0	8.0	1.9	1.8	0.6	0.6	0.8	1.0	1.7	1.1
Low technology	3.7	4.2	2.3	1.7	1.6	1.2	1.8	2.2	4.8	2.0
Total manufacturing	100.0	100.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[1] Distribution of OECD R&D manufacturing expenditure. [2] The national distribution divided by the OECD distribution. The weighted average per country is equal to 1.0. If above 1 the countries is 'R&D specialised' in the given industry and vice versa if below 1. [3] Not all sub-groups are shown.

Note: Sub-groups are shown in italics.

Source: Adapted from OECD (2000c) Appendix table 28.

Table VI Segmentation of the ICT sector in NACE codes.

Activity	Segment	NACE	Description
Hardware manufacturing	Computers	3001	Manufacture of office machinery
		3002	Manufacture of computers and other information processing equipment
		3130	Manufacture of insulated wire and cable
	Communication Equipment	3210	Manufacture of electronic valves and tubes and other electronic components
		3220	Manufacture of radio and television transmitters and apparatus for line telephony/telegraphy
		3230	Manufacture of radio and television receivers, sound/video recording or reproducing apparatus and associated goods
	Instruments	3320	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes (except 3330)
		3330	Manufacture of industrial process control equipment
Services	Wholesale	5143	Wholesale of electrical household equipment appliances and radio and television goods
		5164	Wholesale of office machinery and equipment
		5165	Wholesale of other machinery for use in industry, trade and navigation
	Telecommunications	6420	Telecommunications
	ICT Services and Consulting	7133	Rental and leasing of ICT equipment
		7210	Hardware consultancy
		7220	Software consultancy and supply
		7230	Data processing.
		7240	Database activities
		7250	Maintenance and repair of office, accounting and computing machinery
		7260	Other computer related activities

[1] ICT has been defined as ISIC Rev. 2 classes 3825 (computers), 3832 (radio, TV and communications equipment) and 72 (communications services).

[2] The dominant telecom operator (previous incumbent government monopoly) TDC has announced launch of 3G services in late 2005, which apparently has increased the magnitude of infrastructure investments.

[3] See www.norcom.dk.

[4] Denmark was claimed to have a market share for optical fibers in the area of 7-8% at some stage in the 1990s.

[5] In Germany, France and the UK the license costs have added up to more than $ 100bn.

[6] This has caused a clear demand for upgrading the present 3G technologies. A high speed access variant, HSDPA, is close to being introduced in some networks at present. It may increase transmission speed up to the magnitude of 2Mb/s, but it still remains to be seen.

[7] See Ministry of Research and Information Technology (2004) for a detailed list.

[8] Such as Bang & Olufsen, Radiometer, Thrane & Thrane and RTX Telecom.