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Technological Life Cycles: Regional Clusters Facing Disruption

by

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Abstract
The phenomenon of technological life cycles is argued to be of great importance in the development of regional clusters. New 'disruptive' technologies may initiate the emergence of new regional industrial clusters and/or create new opportunities for further development of existing ones. However, they may also result in stagnation and decline of the latter. The term disruptive refers to such significant changes in the basic technologies that may change the industrial landscape, even in the shorter run. The paper examines the key features of a regional cluster, where the economic development patterns are quite closely related to the emergence of new key technologies.

Keywords: Technological life cycles, regional clusters, communication technology

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1 Introduction

Since the early 1990s, the literature on the importance of geography for economic development has been revitalized. Inside the economics profession Krugman (1991; 1995) has engaged in a 'crusade' aiming at integrating the spatial dimension into mainstream economic theory. This has borne fruit in such theoretical work as Fujita et al. (1999) as well as influenced e.g. the discussion on income convergence versus divergence among European regions. Krugman's writings also caused a comprehensive but rather hostile reaction from the community of economic geographers during the 1990s, surveyed by Martin and Sunley (1996) and Martin (1999).

In 1990 another stream of literature dealing with the geographical dimension of economics emerged from research rooted in a management perspective, in terms of Porter's (1990) highly influential reinterpretation of Dahmén's (1970; 1988) development blocks as regionally based *industrial clusters*. Also emerging in the early 1990s was the literature in *innovations systems*, whether national (Lundvall 1992; Nelson 1993), regional (Cooke 1992) or based on specific technologies (Carlsson and Stankiewicz 1991) or broader sectors (Breschi and Malerba 1997). Technical change and its diffusion has been a core driver of the innovation systems literature as well as in Porter's work. They share the view that the traditional linear model, where scientific discovery and invention move on to industrial innovation in a fairly simple manner, cannot explain the dynamics of industrial development, neither at present nor historically. On the contrary, they share an emphasis on the systemic character of technical innovation - the institutional set-up matters as do interaction among a great deal of actors, such as firms, universities, industry associations, standardisation bodies, government regulators (at the national as well regional level), science parks etc. While the innovation system literature has emphasized the role of inter-firm co-operative networks, Porter on the other hand emphasized local competition as a main dynamic force in the development of clusters.

Recently, major attempts to synthesize and integrate these various lines of work have been presented. *The Oxford Handbook of Economic Geography* (Clark, Feldman et al. 2000) represents a great effort to bring together the various contributions, although without necessarily solving the differences between the various approaches; there is still a rather large gap between mainstream economics and the other approaches. Edquist's (1997) represents the various contributions to the innovations system literature, which to a large extent appear to have been integrated through that effort.[1] Porter (1998; 2000) contains an effort to integrate the management perspective further with the emerging research tradition in economic geography and innovation systems.

The various lines of research on the interaction between territory and industrial development have, thus, somehow tended to converge more recently. Major efforts to do empirical comparisons of regional innovation systems have been performed in several European projects during in the most recent half a decade or so with an early proponent of the concept of regional innovation systems as a central node, see e.g. Braczyk et al. (1997), Cooke et al. (2000) and Cooke (2002). These studies have focused on the most important innovation networks as the supposed core drivers of

[1] See also Freeman (2002), Lundvall et al. (2002), Malerba (2002) and Carlsson et al. (2002) and for more recent state of the art surveys.

regional economic development in such regions as Wales, Baden-Württemberg, The Basque country in Spain, Wallonia in Belgium, the Tampere area in Finland and Styria in Austria.

The present paper is focused on a particular line of research in this context, that of high technology based regional clusters. For obvious reasons this is inspired by studies of some of the archetype examples, such as Silicon Valley, Boston Route 128, the Cambridge Phenomenon, etc. The paper does not aim at being a survey of the studies of these. It deliberately concentrates on a single small cluster, focused on basically one pool of common knowledge, wireless communications technologies - concentrated geographically in a small region, that of North Jutland, Denmark. This narrow focus makes it possible to study a precisely defined regional cluster with a particular focus on its dynamic development over time. The paper will, though, relate this cluster to the economic development of the entire region, but it does not aim at analyzing whether the region of North Jutland fulfill the criteria of being a regional innovation system as summarized in Cooke (2001).

Many of the available cluster studies in the literature have been focused on more static descriptions of their characteristics at a given point in time, although flavoured with evidence of some of the main features of their history. But a more systematic focus on the development of specific clusters over longer time spans has somehow been given less priority. This may be due to the great variety of regional clusters, which differ along many dimensions. Generalisations across this variety may seem difficult, especially concerning development patterns over time. The present paper intends to focus on exactly this issue in terms of developing the ideas of technological life cycles a bit further and apply them on a single case over an extended period of time.

Recent work by Bresnahan et al. (2001), which is a summary of an international project comparing a series of clusters including Saxenian and Hsu's (2001) study of the mutual relations between Taiwan and Silicon Valley, contains international comparisons of clusters as well analyses of their characteristics over time. Their point of departure is Saxenian's (1994) widely read comparison of the salient features of the regained dynamics of Silicon Valley in the early-mid 1980s vis-à-vis the, claimed, opposite features of the Boston Route 128 area.

In the theory of the patterns of technical innovation the concepts of product, industry and technological life cycles seem fit to a more dynamic analysis of the development of regional clusters. Klepper's (2002) analysis of the early concentration of the automobile industry in Detroit is an example of the merit of the industry life cycle approach, presented a more general level in Klepper (1996). For detailed analysis of clusters in electronics the theories of technological life cycles seem fit because a given cluster often experience the passing of several life cycles. It is the capability of a cluster to adapt to these continuous 'bombardments' of new technologies, which is the core field of study. Saxenian's account of the history of Silicon Valley is closely related to the emergence of radical new technologies, as is her analysis of how the Route 128 region got stuck in one, at the time highly successful, technology – i.e. minicomputers, represented by then such successful firms as DEC and Data General. Two new technological life cycles (Unix based 'workstation computers' and the PC) were at the heart of the Silicon Valley resurgence in the 1980s, when the Boston area, according to Saxenian, was left behind in the computer industry. [2]

[2] This analysis has not gone unnoticed. To some extent it has been misinterpreted as if the Boston area was left behind in general, which is far from being the case in a series of technologies, where Boston universities and firms are world leaders today.

In the Bresnahan et al. cases there are, however, some inherent problems in the level of aggregation. Silicon Valley is compared with e.g. wireless communications of the Nordic countries - which by the way contains a series of distinct regional clusters in this field; India; Taiwan; Ireland and Israel. A more precise definition or at least set of principles for delimitation of clusters appear to be somehow missing in much of the cluster literature, as also emphasized by Maskell (2001). Here Porter (1998) provides one of the most operational approaches:

> "*Clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions in a particular field, linked by commonalities and complementarities*." (Porter 1998, p.199)

In his analysis of what might lead to decline of a cluster, Porter (1998) also emphasizes the technological component:

> "*External threats to cluster success arise in several areas. Technological discontinuities are perhaps the most significant, because they can neutralize many cluster advantages simultaneous*" (Porter 1998, p.244)

New 'disruptive' technologies may therefore initiate the emergence of new regional industrial clusters or create new opportunities for further development of existing ones. However, they may also result in stagnation and decline. The term disruptive refers to such significant changes in the basic technologies that may change the industrial landscape, even in the shorter run. Tushman and Anderson (1986) describe the disruption as, a technological discontinuity that is so significant that no increase in scale, efficiency or design can make the older technologies competitive with the new technology.

In the present paper we have chosen to focus on the evolution of a fairly small cluster of wireless communications technology in North Jutland, Denmark. It is geographically as well as technologically delimited to mobile communications in one county. This field is part of a slightly larger cluster of wireless communications technologies including its 'ancestor', maritime communications.[3] The following section 2 focuses on the concepts of technological life cycles and the creators and 'disrupters' of these, while section 3 deals with a series of dimensions in the analysis of cluster dynamics over time. Section 4 introduces the cluster in its regional context, while section 5 contains the analysis of the interaction of various generations of mobile communications technologies, other wireless technologies and the dynamics of the cluster. Section 6 concentrates on the future perspectives and the role of policy. The main questions of the paper are. Will the coming third generation mobile communications technologies dominate the future of the wireless industry? Is the North Jutland cluster amply prepared for such a scenario or will the future bring alternative disruptions from e.g. the field of wireless access to the Internet?

2 Theory of technological life cycles and disruptive technologies

The transformation and change of sectors, industries or products is, in the literature on industry life cycles (Klepper 1996) and product life cycles (Abernathy and Utterback 1975), shown to follow a life cycle from birth to maturity. In Abernathy and Utterback (1975) the model is applied to tech-

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[3] For an account of the early development of this cluster, see Dalum (1995).

nological innovation, where product and process innovations are integrated into a single model explaining technical change in the evolution of a product life cycle.

In the beginning of the product life cycle (the fluid phase), there is a lot of experimenting with different designs etc., resulting in a high number of product innovations. The early phase with a lot of radical product innovation turns into a phase dominated by incremental innovations, as a dominant design emerges. As the rate of product innovations drops and technological uncertainty is lowered, the rate of process innovations increases. Consequently productivity increases and production scale grow (Utterback 1994). During the evolution, the focus shifts slowly from product performance maximisation to cost minimisation (the transitional phase). In the following mature phase, the overall rate of innovation fades, the products become standardized and the processes become very efficient and closely integrated with the products.

The industry life cycle and the product life cycle are closely linked.[4] Entry, exit and growth are added to the product life cycle to form the industry life cycle model. In addition to the product life cycle model, the fluid phase of an industry is characterised by a high number of entrants. The number of firms initially rises, but as the industry enters the transitional phase and the number of firms reaches a peak, a shakeout occurs, resulting in a steady decline. The prices also decline during the cycle and while the market size initially is small, it grows rapidly in the transitional phase.[5]

According to the industry life cycle, the organization of the firm and the innovative activity changes during the cycle (Utterback 1994). In the early phase there is high innovative activity among smaller firms and new entrants, while in the mature stage, with less product innovation, there tends to be an advantage in the innovative activity of large and established firms (Audretsch and Feldman 1996; Klepper 1996).

In Cainarca et al. (1992), the industry life cycle is split into (different) life cycles of sub-industries, defined by their technology and the result is a technological life cycle. This is more than the product life cycle, but is less than the industry life cycle. As an example they use electromechanical printers and the introduction of laser printers, which differed in terms of technology and user needs, but still were interdependent and overlapping. Each technological life cycle has different features. *Introduction* with high uncertainty about technologies and markets, clusters of innovation, high risk of sunk costs and search. *Early development* with accelerated market dynamics, persisting uncertainty and risk of sunk costs, focusing on technological trajectories and importance of complementary assets. *Full development* with stabilization of market dynamics, standardization and incremental product and process innovations, as well as a prominent role of complementary assets and resource internalisation strategies. *Maturity* characterized by stabilization of market structures, possible technological revitalization, oligopolistic rents, market manipulation and collusion. *Decline* with contraction of the market, rationalization, concentration and exit strategies.

The typology of technological life cycles can be applied fruitfully on the evolution of mobile communications technologies. The significant changes in the basic technology from the first generation (1G) Nordic Mobile Telephony (NMT) technology to the second generation GSM constitutes a shift of technological life cycles. Likewise is the forthcoming third generation system

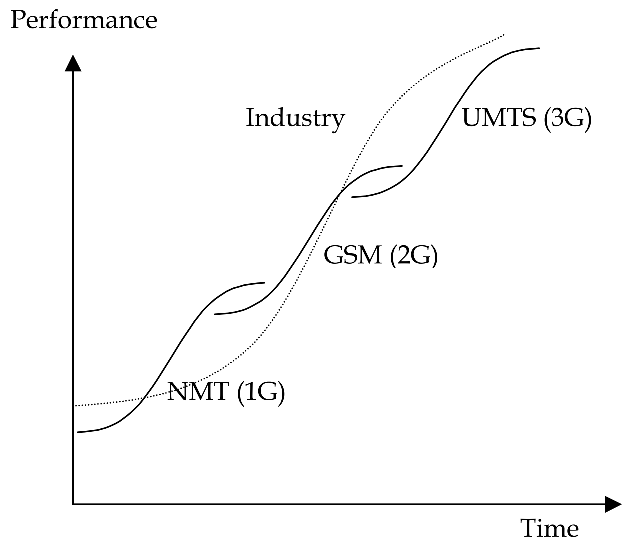
[4] In the reference for the industry life cycle, Klepper (1996) refers to and uses the term product life cycle, but from an industry perspective.

[5] The model is criticised for only being applicable only to certain industries, such as automobiles, whereas other industries differ. This is shown for quality improving product innovations in some high tech industries in Filson (2001).

(UMTS) a new cycle. However the coexistence and shifts of different technological life cycles is not straight forward, but complicated and full of disruption. Hence the technological life cycle can be used to explain these difficulties, which cannot be fully captured by the concepts of industry or product life cycle.

In Utterback (1994) the S-curve model is used to illustrate the life cycle, where the evolution of the technology, industry or product follow an S–shaped curve over time. The performance is usually either measured by technological performance or market penetration. Freeman et al. (1982) show how the miniaturization of electronics from 1940 to 1975 follows an S-curve with parts pr cubic inch as a performance indicator.[6] The technological life cycles of mobile communications are shown in figure 1, where also an 'envelope curve' has been drawn to illustrate that there is a life cycle pattern of the entire industry moving towards the mature stage already at present, due to (temporary?) market saturation of mobile phones in the most dominant markets.

Figure 1 The technological life cycles of the mobile communication industry

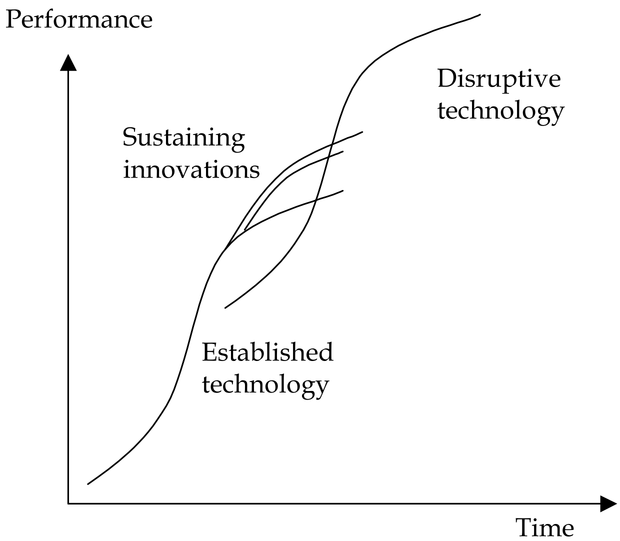


The path of the cycles is of course not as predictable as the diagram may indicate. The life cycle of an established technology may be prolonged by sustaining innovations or may be disrupted by emergence of a new technology. Sustaining innovations are not necessarily incremental, but can be quite radical. A disruptive technology is new and creates a new technological life cycle. Initially the disrupter under-performs the established technology, but it enables new applications for new customers, presents new benefits and the performance improves rapidly. This is described in Utterback (1994) as the invasion of a stable business by radical innovation. The emergence of the latter changes the pattern of the established products. It is shown how disruptive technologies first have a lower performance than the established and it may also have different customers and applications. For a long time the established technology may continue to perform better and the disrupter may not be seen as a threat. Because the disrupter has a different improvement trajectory, it will eventually outperform the old technology, although the latter may fight back by sustaining innovations as shown in figure 2.

[6] The y-axis is a logarithmic scale of parts pr cubic inch and the x-axis is time and different technologies are sketched on the curve.

Utterback uses the American ice industry as an example, but finds a similar pattern in others, such as the computer industry. Tushman and Anderson (1986) categorizes the disruption as product (new product class, substitution, or fundamental improvement) or process disruption (substitution or radical improvement), that is either competence destroying or enhancing. In Bower and Christensen (1995) and Lewis et al. (2001) it is specified, that what disrupts is usually a new business model, applications or customers, but not necessarily the technology itself. The disruption caused by e.g. a new business model is however by its nature closely linked to the new technology and cannot be transferred to the established technology. The disruptive technology often comes from outsiders and not the industry leaders (see Utterback (1994) and Bower and Christensen (1995)). As a result the disruptive technology is very hard to predict[7] and even disrupters may be disrupted. The outcome is often a shift of market leaders and location (Utterback 1994). Likewise a new technological life cycle offers new opportunities for existing or emerging regional clusters. Audretsch and Feldman (1996) show that there is a tendency in the early stages of an industry life cycle for innovative activity to cluster, whereas it is more dispersed in the mature stages.

Figure 2 S-curves for the established and disruptive technology



In the case of mobile communications technology, the 1G cycle consisted of analogue mobile systems, of which the Nordic NMT from 1981 became very successful. This cycle includes in our perspective the incremental improvements from NMT 450 to NMT 900 MHz. The disrupter and subsequent new technological life cycle was the pan-European GSM, which was a shift to digital technology and required a new infrastructure.[8] The disruption caused by GSM not only replaced NMT, but it has nearly become a world standard, which has led to a mass adoption of mobile phones and high growth of the industry. GSM was also a disrupter to e.g. the fixed telephones and the satellite cell phone networks[9] (Mannings and Cosier 2001) as well as in the telecom service provision industry.

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[7] Brower and Christensen (1995) look at disruptive technologies from a management perspective and describe tools for managers to try and predict possible disrupters. As an example they analyse the disk-drive industry and predict, in line with the previous evolution of the disk-drive industry, that the next disrupter would be the 1.8-inch drives. The latter has, however, until now not outsold the 3.5-inch drives.

[8] The less successful US equivalents were AMPS (1G) and D-AMPS (2G).

[9] Before the satellite networks (such as Iridium, ICO and Globalstar) were developed and up running, GSM had conquered most of their conceived potential customers and provided well functioning and cheap service; see also Dalum (2002).

A new technological life cycle is predicted in terms of the third generation of mobile phones (UMTS). Examples of sustaining innovations of 2G are e.g. I-mode in Japan and the 2.5G technologies, GPRS and EDGE. UMTS requires a new infrastructure and is expected to cause disruption by creating access to the mobile Internet as well as the 'wired' Internet. It is however not straight forward, what kind of and how much disruption 3G will cause, partly because of the sustaining innovations, the spectrum auctions, the general crisis of the telecommunication sector starting in year 2000 and other disruptive technologies. Especially WLAN, which is providing low cost, high-speed short distance wireless access to the Internet, is seen as a potential disrupter to the emerging 3G.

3 Regional clustering - main causes and dimensions

The idea of regional clustering is an old one. Several economists have analysed that firms with similar or related activities often have been located in the same region (Marshall 1920; Perroux 1950). In the 1990s a large amount of literature on this topic has emerged in the field of economic geography and different sub-disciplines of economics; it has regained esteem. This was mainly a result of increasing awareness of the importance of (relative) immobile factors such as skills, knowledge and the institutional set-up for innovation, competitiveness and growth.

A regional cluster is a geographically concentrated group of firms and related organisations active in similar or closely connected technologies. The firms are interconnected by formation of specialized local labour markets and institutional set-ups. The main forces behind spatial clustering are the classical Marshallian externalities (Marshall 1920; Krugman 1991): (i) economies of specialisation caused by a concentration of firms being able to attract and support specialised suppliers, (ii) economics of labour pooling, where the existence of a labour force with particular knowledge and skills attracts firms, which again attract and create more specialised labour and (iii) technological externalities and knowledge spillovers, where knowledge and information flow between the actors in the cluster, mainly by way of labour mobility and networks.[10]

Another factor behind co-localisation of firms is the reduction of transaction costs. When users and producers are located near each other, negotiations and monitoring become less costly. This is especially true when communication is based on personal contacts. One main finding in innovation studies is, that the central part of the required knowledge is difficult to codify and therefore close interaction among actors is important in the innovation process (Lundvall 1992). Trust also has a geographical dimension; it based on cultural similarities and familiarity with transactions partners (Piore and Sabel 1984). Other researchers have found that geographical concentration of firms attracts sophisticated buyers from the outside (Oakey 1985; Russo 1985). These buyers often provide insights concerning advanced demand features. Other demand and supply side effects can be added, such as sophisticated local demand, access to resources or special infrastructure (Porter 1998; Enright 2001). Rather sophisticated support and service activities like venture capital, experienced entrepreneurial and managerial knowledge and science parks may also be important for start-ups and subsequent cluster evolution.

The innovation systems literature (Lundvall 1992) emphasize close proximity between production and related innovation. Innovative activity is often based on tacit knowledge that may require

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[10] Breschi and Lissoni (2001) have argued that a good deal of research in economic geography has put an exaggerated emphasis on technological externalities and too little on the importance of labour pooling.

face-to-face contact among development engineers. Innovation is also often an experimental process where researchers achieve new knowledge from the production process and use this in laboratories. Therefore, innovative activity has a tendency to cluster in the same areas as where production is localized, as shown by (Audretsch and Feldman 1996), who have analysed the relation between industry life cycles and the tendency to spatially cluster in production and innovation activity in the US. They classified 210 industries (4-digit SIC) in four stages of an industry life cycle and used the states as their level of analysis. Spatial clustering of innovative activity differed along the stages of the industry cycle. The clustering seems to be strongest in the early stages and more disperse in the later ones.

Clusters may differ along various dimensions. Enright (2001) has proposed a series of dimensions, which are condensed to five below. By definition *geography* itself is central. Some regional clusters are highly localized, others more dispersed.

Another central dimension is *depth*, which refers to the range of vertically related industries within the cluster. A deep cluster contains an almost complete supply chain, whereas a shallow cluster relies on inputs from outside the region. The horizontal dimension is important, too. Horizontally related industries are sharing common technologies, end users, distribution channels and other non-vertical relationships. A cluster is said to be broad if it consists of several horizontally related industries. *Breadth* of a cluster will normally be a sign of strength. Externalities related to a pool of skilled labour are important. Maskell (2001) and Kenny (2002) stress the importance of experimenting and testing different technological paths in concentrations of horizontally related firms. By co-locating firms learn from each other's failures and successes and are able to monitor, discuss and compare alternative solutions.[11] Thereby they participate in a continuous learning process by watching competition, compare different solutions, select, differentiate, imitate and add own ideas. And some of the horizontally divided industries may have opportunities to avoid temporary decline of markets. From a cluster point of view the risks are spread in a broader cluster.

The vertical (depth) and the horizontal dimensions (breadth) constitute the potential strength of the cluster. However, the dynamics of both depth and breadth can be further enhanced by appropriate knowledge organisations. Of special importance is the presence of *university R&D and education* supporting different industries on the horizontal as well as the vertical axis in figure 3. It is e.g. a potential weakness if local research activities are limited to only one part of the value chain. Or if important parts on the horizontal axis are not matched locally by appropriately educated engineers.

The three dimensions shown in figure 3 may be said to represent the activity base of a given cluster. But it may not only be the mere existence of activities along each of the axes that may be of importance but also their *density*. Dense clusters consisting of a large number of firms, some of which may be large, may have a higher probability of success than more 'sparse' ones.

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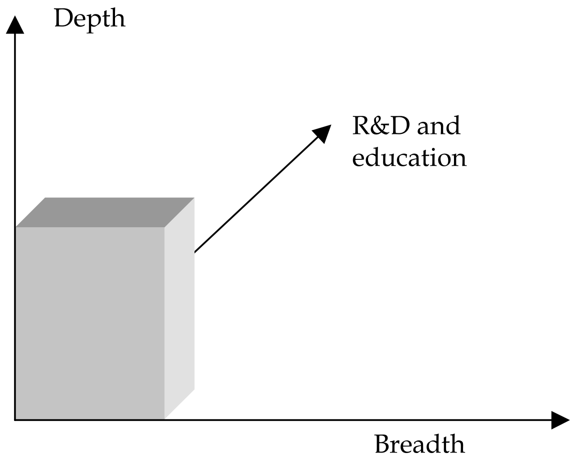
[11] In discussing the importance of context in shaping the U.S. Internet industry Kenny (2002) argues that the start-ups in Silicon Valley benefited from the knowledge gained from the concentration of previous start-up attempts and advanced customers.

Figure 3 Characteristics of a regional high-tech cluster



A final dimension to be taken into account is the *ownership structure*. The role of multinational companies is a critical factor. The literature on regional clusters has arguments for both positive and negative effects of MNCs. On the one hand multinationals can fill holes in the local knowledge base and support the firms in the region with financial resources in high-risk development activities. Likewise the presence of MNCs may have high promotional value and thereby strengthen the image of the cluster. On the other hand, the presence of multinationals may weaken the interaction among local actors. The capacities of a cluster may be hampered by MNC acquisitions because it may break up patterns of networking amongst incumbent firms. Another potential negative effect is the lack of decision-making power in the region. This may lead to a loss of market knowledge and make it more vulnerable to strategic decisions not related to local conditions.

The factors fostering initial emergence of a cluster may be very different from those supporting its further growth (Bresnahan et al. 2001; Enrigth 2001; Porter 1998). During cluster evolution different congestion effects may appear and the internal dynamics of networks and organisations may become less flexible. The stages of cluster evolution are, however, not predetermined, and revitalisation may, or may not, occur.

4 North Jutland – structural catching-up and the emergence of ICT

North Jutland is the county at the northern tip of the peninsula of Jutland, which is the part of Denmark connected to the European continent. The population is around half a million people, slightly less than one tenth of the Danish total. The total employment was 246,500 persons in 1999, of which the private sector share was 163,500. The region has traditionally been characterised as peripheral with an unemployment rate among the highest in Denmark. The industry structure has previously been dominated by more traditional industries, such as agriculture and food processing, fishery, tourism, shipyards, textiles, tobacco and cement.

However, during the late 1980s and the 1990s the region has experienced a process of structural change, which has transformed the structure of the private sector. There are 16 counties in Denmark of which the greater Copenhagen area and Aarhus can be distinguished as having a more 'metropolitan' industry structure, specialised in knowledge intensive services, but not in the primary sector or manufacturing industry. North Jutland has caught up to the characteristics of the 'non-metropolitan' regions during the 1990s as indicated in table 1, which shows the relative employment shares in the 1990s of the region vis-à-vis the national average. The 'non-metropolitan' regions are specialised in the primary sectors and manufacturing industry and not in the knowledge intensive services. North Jutland became specialised (i.e. got an above average employment share) in especially mechanical engineering as well as in electronics. The latter has been among the features, which point at the region not being peripheral any more. The industry structure is at present in line with the average Danish 'non-metropolitan' counties.

Table 1 Employment structure in North Jutland - the private sector

	North Jutland						Denmark
	Speciali-sation 1992	Speciali-sation 1999	Employ-ment (persons)	Share of employ-ment (percent)	Development 1992-99 (1992=100)	Change (persons)	Development 1992-99 (1992=100)
Agriculture, hunting and forestry	**1.59**	**1.48**	14,284	5.79	72.5	-5,417	77.3
Food, beverage and tobacco	**1.44**	**1.54**	11,227	4.55	94.6	-640	87.7
Textiles and textile products	0.73	**1.05**	1,477	0.60	81.9	-326	57.1
Wood and paper, publishing and printing	0.81	0.95	6,230	2.53	115.7	847	98.7
Refined petroleum products etc.	0.05	0.05	3	0.00	75.0	-1	82.8
Chemicals	0.30	0.19	460	0.19	73.8	-163	114.1
Rubber and plastic products	0.54	0.65	1,267	0.51	127.9	276	105.9
Other non-metallic mineral products	**2.15**	**1.81**	3,557	1.44	96.0	-149	113.1
Basic metals	**1.35**	**1.44**	1,293	0.52	138.6	360	128.9
Fabricated metal products	**1.26**	**1.33**	5,332	2.16	101.7	90	96.3
Machinery and equipment	0.91	**1.02**	6,282	2.55	109.8	561	97.7
Electrical and optical equipment	0.84	**1.19**	5,084	2.06	154.1	1,785	108.9
- Office machinery and computers	**1.22**	**1.80**	340	0.14	106.6	21	71.5
- Electrical machinery and apparatus	0.60	0.74	1,198	0.49	148.6	392	121.2
- Communication equipment and consumer electronics	**1.63**	**2.53**	2,887	1.17	172.1	1,209	110.4
- Medical equipment, instruments, watches etc.	0.39	0.50	659	0.27	132.9	163	102.5
Motor vehicles etc.	1.00	0.76	525	0.21	97.8	-12	127.9
Other transport equipment	**2.67**	**2.27**	2,017	0.82	54.1	-1,713	63.4
Furniture and miscellaneous	0.88	0.74	2,151	0.87	82.6	-453	97.8
Recycling	**1.32**	0.94	34	0.01	53.1	-30	73.9
Construction	1.00	**1.10**	16,436	6.67	132.0	3,988	119.4
Wholesale and retail trade, hotels and restaurants	0.99	0.98	44,115	17.89	110.8	4,296	111.7
Transport, storage and post	0.75	0.78	11,443	4.64	105.4	584	100.0
Telecommunications	0.63	0.99	1,777	0.72	197.9	879	124.3
Financial intermediation	0.80	0.76	5,160	2.09	84.0	-981	88.2
Real estate activities	0.91	0.92	2,767	1.12	104.6	122	102.5
Renting of machinery and equipment	0.58	0.72	425	0.17	154.5	150	124.4
IT service	0.72	0.63	1,942	0.79	171.4	809	194.2
Research and development	0.16	0.37	369	0.15	354.8	265	149.0
Other business activities	0.78	0.77	12,541	5.09	137.8	3,440	139.4
Recreational, cultural and sporting activities	0.71	0.76	3,374	1.37	128.0	739	119.4
Other service activities	**1.06**	**1.01**	1,962	0.80	94.5	-114	98.4
Total private employment	1.00	0.99	163,534	66.3	106.0	625	106.0
Total employment	-	-	246,546	100	106.3	9,192	106.2

Note: Specialisation is the relative share of employment in a sector compared to the national average i.e. a number above 1.0 indicates that the municipality is specialised.
Source: Statistics Denmark.

The process of structural change has been speeded up by the relative fast economic growth in Denmark in the 1990s, where aggregate unemployment decreased from a level of 12% in 1992-93 to 5-6% at present. At the turn of the millennium the national rate of unemployment was 5.4%, but the rate was 7.2% in North Jutland, still the second highest among the 16 Danish counties. In an international context an unemployment rate slightly above 7% and a per capita income of approximately US $23,000 (88% of the national average, based on 1998 GDP data) cannot qualify for being a poor region. But although the region has caught up according to the structural dimension, the average annual GDP growth 1993-98 was 2.5% compared with the national growth rate of 3.3%. The North Jutland growth has been the third slowest among the 16 counties.

The presence of a fairly visible segment of the ICT sector is of a rather recent origin in the region. Table 2 shows the structure of ICT employment compared to the national average in the 1990s.

Table 2 The structure in the ICT sector in North Jutland – the private employment

	North Jutland						Denmark		
	Speciali-sation 1992	Speciali-sation 1999	Employ-ment (persons)	Share of ICT (percent)	Development 1992-99 (1992=100)	Change (persons)	Share of ICT (percent)	Development 1992-99 (1992=100)	Export spe-cialisa-tion (1998)
Manufacturing	**1.05**	**1.51**	3,731	44.9	**150.3**	1,248	25.3	**104.3**	0.52
Office machinery	**4.33**	**6.81**	288	3.5	**116.1**	40	0.4	73.7	0.15
Computers	0.70	0.36	52	0.6	48.1	-56	1.5	94.4	0.41
Electronic components and wire	**1.55**	**1.14**	511	6.2	81.2	-118	4.6	**110.2**	0.21
Telecommunications equipment	**3.13**	**5.92**	1,936	23.3	**207.3**	1,002	3.4	**109.5**	**1.14**
Consumer electronics	0.27	0.89	467	5.6	**392.4**	348	5.4	**120.1**	0.78
Electro medical	0.48	0.42	193	2.3	84.3	-36	4.7	95.5	**1.70**
Instruments etc.	0.41	0.55	284	3.4	**131.5**	68	5.3	98.1	0.94
Service	0.53	0.63	4,573	55.1	**176.2**	1,978	74.7	**147.7**	-
Wholesale	0.33	0.35	846	10.2	**137.6**	231	24.5	**127.9**	-
Telecommunications	0.62	0.99	1,777	21.4	**200.8**	892	18.4	**125.2**	-
IT service and software	0.67	0.63	1,950	23.5	**178.1**	855	31.9	**190.1**	-
Total ICT sector	0.70	0.85	8,304	100	**163.5**	3,226	100	**133.7**	-

Note: Instruments etc. are instruments and equipment for detecting, measuring, checking and controlling physical phenomena or processes. The export specialisation is based on trade by commodities statistics for OECD (23).
Source: Statistics Denmark and OECD (2000) *International Trade by Commodities Statistics*, No. 1.

The total ICT employment was 8,300 in 1999 of which 45% of the jobs were in manufacturing compared to 25% for Denmark on average. The North Jutland specialisation in manufacturing of ICT increased during the 1990s from just above 1 to 1.5 and jobs are concentrated in two manufacturing industries, telecommunications and electronic components. Specialisation in telecommunications hardware has been outstanding with an increase from a 3 to a nearly 6 times larger employment share compared to the national average.

The region is not specialised in ICT services at the aggregate level where specialisation only increased from approximately 0.5 to 0.6 1992-99. In telecommunications services the region is however at the national average, which is only the case in a few counties. This industry is heavily concentrated in the two 'metropolitan' regions. In North Jutland case this contains a non-R&D oriented section of the previous monopoly operator TDC and the main part of the first private operator of GSM (2G) mobile communications in Denmark, Sonofon. The specialisation pattern at the municindergraduate level engineering schools both with departments in electronic engineering. During the 1970s a few maritime communications firms emerged as spin off's from SP Radio. At the beginning of the 1980s North Jutland had become visible in an industrial context as a maritime communications and printed circuit board concentration. At the university side the first M.Sc.'s in

ustrial development was the start of Aalborg University in 1974, which integrated two previous

isruption in the context of a regional cluster These statistical patterns cover a wireless communications cluster in North Jutland consisting of two related fields, mobile telephony (development and production of hardware and telecom ser-vices) and equipment for maritime communications and navigation. This cluster, called NorCOM from 1996, originates back to the mid 1960s when the 'mother' company SP Radio switched from being a consumer electronics producer for the domestic market to radio telephones for small ships. This firm quickly became one of the world leaders in its field. An important trigger for further in-electronic engineering graduated in 1979 and research activities were growing rapidly. Figure 5 shows the family tree of the NorCOM cluster.

Figure 5 Cluster relations diagram

Source: NorCOM homepage (http://www.norcom.dk)

5.1 The NMT (1G) life cycle – an embryo of a cluster formed

From 1981 the Nordic mobile telephony operators (incumbent government owned monopolies) launched the first cross national public mobile telephony system ever seen, the NMT.[13] It was an analogue system working at the 450 MHz frequency band. The terrain was divided in hexagonal areas and in the centre of each of these was a 'base station' which contained the connection to the wired telephone system and the facilities for 'roaming' the signals from one hexagon to another while the users were on the move. This system became an enormous – and unexpected - commercial success in term of user penetration, which called for significant attention internationally. The main producers of the equipment was Swedish Ericsson, which was the unchallenged leader in infrastructure equipment, and Danish Storno, located in Copenhagen, being strong in terminals (taken over by US General Electric in 1976).

A new technological life cycle had emerged and barriers to entry were smaller at the early stage, at least for the terminals market. Among the new entrants was Finish Nokia, a 100-year-old company in the paper and rubber industry, who acquired the Mobira start up, and the North Jutland firm, Dancall, which started as a maritime communications spin off from SP Radio. The 1980s became the decade of the 1G life cycle. Growth was very rapid for Ericsson, Nokia, Dancall and Storno. The business opportunities appeared very promising, but competition also increased – prices and size of the terminals decreased, while technological performance increased rapidly. While the next generation of systems could be seen in the horizon, Storno was sold to the dominant terminal producer Motorola in 1986. In North Jutland another maritime communications start up from the 1970s Shipmate also entered the NMT field in 1985 as Cetelco.

The development of the NMT mobile industry is an archetype of a technological life cycle. There were other systems available, especially the AT&T AMPS system and TACS from Motorola only used in the Americas, as well as a few unsuccessful systems, such as the German C-system. There was a substructure in terms of a 1G (450 MHz) and 1.5G (900 MHz), respectively, but the basic infrastructure was the same. Cetelco entered the industry by focusing on 900 MHz based equipment as an example of new opportunities being opened when the sustaining innovation of 1G+ emerged.

At the end of the 1980s North Jutland became internationally visible as an NMT region. Several of the large telecommunications multinationals had entered the NMT terminals market, such as Siemens and Alcatel. The first Alcatel terminals were thus developed in North Jutland by T-Com in 1986, a spin off from Dancall – to become acquired by Korean Maxon in 1991.

5.2 The GSM (2G) life cycle – the regional cluster consolidated

During the last half of the 1980s a new life cycle was emerged. The tremendous success of NMT inspired the European telecommunications operators to create a Pan-European system, but entirely based on digital technology. This process was given strong political backing by becoming a Europe

[13] The first cellular wireless system was, however, developed in the US by AT&T; the basic idea was demonstrated at Bell Labs already in 1947. A prototype of the AT&T's 1G AMPS system was tested in 1978 in Chicago, but due to a series of complications, mainly rooted in the ongoing antitrust case against AT&T, the 1G analog system was first launched commercially in the US in 1983. See West (2000; 2002) for detailed analyses of the causes of the late start for wireless services in the US.

1992 'flagship project' (Financial Times 1988). The standardisation process of the GSM system was taken over by a new EU organisation, the European Telecommunications Standards Institute (ETSI). The GSM system was planned to become operational in 1992 and a large amount of prestige and political momentum was embedded in the entire process.

GSM – and its competing 'sisters' in the US and Korea, D-AMPS and CDMA – represented an entire new technological life cycle. The infrastructure had to be rebuilt in terms of antennas and base stations in the landscape. The technological challenges for developing this new infrastructure as well as the GSM terminals were huge. A veritable race began because many of the incumbent telecommunications hardware producers saw the commercial opportunities already harvested by Ericsson, Storno/Motorola and, not least, Nokia in the second half of the 1980s.

The challenges were of such a magnitude, that the some of the major multinationals formed pre-competitive alliances for developing parts of the equipment. Nokia, until the 2G cycle not active in infrastructure equipment, formed with Alcatel the ECR900 consortium to develop GSM infrastructure technology (Dalum 1993). Ericsson cooperated with Siemens at some stage during the 1988-92 period as part of the contract of building the Deutsche Telekom 2G infrastructure.

In the North Jutland context the advent of GSM was a major challenge and also seen by many as a major threat, given the character of the small and medium sized firms. GSM was no doubt seen as a major disruptive phenomenon in the horizon. However, local university (AAU) research had flourished during the NMT boom and the interaction with the local industry thrived. The knowledge infrastructure of the region began to become visible internationally. The two local producers and competitors, Dancall and Cetelco, announced in 1988 a pre-competitive joint venture, DC Development, to develop the basic technology for GSM terminals - located on neutral ground at the newly founded Aalborg University science park, NOVI. The two firms explicitly planned to close the joint venture when the mission was accomplished and compete based on different features of the terminals, such as design.

The DC Development team peaked at approximately 30 persons in 1992 and managed to develop a GSM terminal presented at the annual CEBIT fair in Hannover, Germany in 1992. At the time terminals were presented by only a handful of companies, including Ericsson, Motorola, Nokia and Dancall-Cetelco (in various disguises such as Philips, Hagenuk and Dancall). This innovative effort by the small North Jutland firms basically drained them completely financially. Both were taken over by foreign companies. Dancall was acquired by UK Amstrad, then by Bosch and later again by Flextronics and Siemens. Cetelco was taken over by German Hagenuk, to be sold later to Italian Telital.

At this stage, the first private GSM operator Sonofon[14] decided to build its main operations in Aalborg and the AAU research profile was consolidated by a new research centre CPK, which 1993-2002 became an important international actor at the research scene in wireless technologies.

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[14] The European telecom regulation set-up required from the beginning of the GSM phase at least two operators with nationwide coverage in each country. The result was heavy competition not least in the 'lead user' Nordic countries. Their previous monopolies, the government controlled incumbents, were broken leading to fierce competition, even in the early stage with only two operators. Sweden became the first country in the world with four nationwide GSM operators. Competition in the service industry appeared to be strongest in the Nordic countries, although the character of regulation was very different from the US system. The key feature was the requirement of nationwide coverage, which led to very fast diffusion of 2G technology in these countries. They maintained their lead from the 1G cycle in terms of the highest per capita penetration ratios.

But there was a widespread fear at the time, that the (planned) closing down of DC Development would be the end for the region in GSM. However, instead of dying this group of industrial development engineers managed to start a cloning process – through existing firms or via spin off's - which resulted in the region becoming a development hub for GSM terminal development with six-seven firms developing GSM equipment (2G and 2G+), basically for foreign companies.

The latter half of the 1990s became a period of very rapid growth for the cluster. To some extent the events of the late 1980s were replicated but on a significantly larger scale. And what became more and more evident already from the early 1990s were the contours of a wireless communications cluster, to a certain extent based on close personal interaction between engineers with a high degree of inter-firm mobility.[15]

During the 1990s this cluster was widened *horizontally*. After the financial collapse of Dancall in 1993, the cordless phone department was sold to the German DeTeWe as CorTech. A standardisation project involving five-six Danish firms and Ericsson founded Dansk DECT Udvikling focusing on further specification of the ETSI standard for cordless phones. A group of engineers left Dancall and were joined by a group from Maxon to found RTX, which during the decade became a world leader in developing DECT phones for big companies on OEM terms. In the second half of the decade RTX decided to enter 2G (and recently 3G), but in CDMA technology.

Another field to widen the breath was the emergence of the Bluetooth standard. Digianswer and RTX entered this field very early and the former was for that reason taken over by Motorola in 1999. The DECT development consortium was taken over by Ericsson and continued as a DECT unit but also went into Bluetooth development. Lasat developed early in the 1990s modems for mobile phones, but gradually concentrated on modems for wired telecommunications. Another group, Danphone, was spun off from Dancall already in 1990 to focus on 'closed' communications systems. Already in 1985 a development group left a predecessor to Dancall and formed Niros, also focused on closed systems and later on TETRA (closed systems on a public network for use by police, transport companies, etc.). In 1998 LH Comlog was spun off from LH Agro to focus on management of truck fleets by combining GPS technology and GSM.

Parallel to the horizontal proliferation of the cluster, a *vertical* deepening was also seen. The first significant event was the decision to locate the major activities of the first private mobile phone operator Sonofon in Aalborg from 1991, which resulted in nearly 1000 jobs at the end of the decade. This deepening was matched later on by upstream entrance of specialised component developers, especially marked when one of the US leaders in chip sets for mobile phones Analog Devices opened an affiliate in Aalborg in 1997. Analog delivered chipsets for two of the local terminal developers and wanted to be present at the now thriving GSM development hub.

This deepening was brought further by the Texas Instruments acquisition of a GSM developer ATL in 1999. Texas, the world leader in Digital Signalling Processors (DSP), also wanted a presence in this environment and did so by being engaged directly in developing terminal equipment. A parallel strategy was followed by Infineon, one of the largest semiconductor companies in Europe (and owned by Siemens), which founded DWD a small GSM developer in 1999. The Franco-Italian STMicroelectronics entered in 2000. Two Cambridge firms – Cambridge Silicon Radio and

[15] In Dahl (2002) and Dahl and Pedersen (2002 forthcoming) the inter-firm mobility of engineers and intra-cluster knowledge flows between engineers have been studied in detail.

TTPCom – both specialised in delivery of specialised software for GSM terminals entered the cluster in 2001. Also in 2001 the DECT firm Cortech was taken over by the German Rohde & Schwarz and transformed to a local affiliate of this world leader in test equipment for 2G equipment. In parallel to these upstream entrants, a downstream newcomer was founded in 2000 as End-2-End Wireless focusing on delivery of content packages to the mobile phone operators. The financial foundation was delivered by corporate venture capital from HP, Cisco and Deutsche Bank and the manger of the firm was the previous head of Sonofon Aalborg.

The third dimension in figure 3 – *university R&D and education* – thrived further in the late 1990s, when CPK at AAU was prolonged with a second major research council grant 1998-2002. All over Europe there was a general lack of electronic engineers in the late 1990s. Any region that could offer qualified engineers and an innovative research environment in the wireless field could attract multinational companies – and North Jutland indeed did.

At the end of the decade the GSM developers moved into sustaining 2G+ solutions, GPRS and Edge, who are able to e.g. speed up the data communication performance of GSM solutions. This marked the beginning of the next major technological life cycle 3G, which in an ETSI context is the UMTS standard also adopted in Japan by NTT DoCoMo. At the US scene this is competing with the Qualcomm developed CDMA2000. Condat, formed by local engineers as an affiliate of a German company, was quickly taken over by Texas Instruments in Aalborg after having developed innovative protocol stack solutions for 2G+. In general major players in the industry were attracted by the viability of NorCOM and saw opportunities as using the region as also a development hub for 3G technology. This was the explicit aim by Nokia and Ericsson when they founded 3G development units in North Jutland in 1999.

In 1999 and the first half of 2000 the NorCOM cluster, thus, became clearly visible on the international scene, but dark clouds appeared in the horizon.

5.3 Is UMTS (3G) a major threat?

The emergence of 3G as a new technological life cycle is also expected to create disruption, but the telecommunications turmoil began long before the expected roll out of 3G networks.[16] The turmoil is caused by the 'global' crisis in the ICT sector that started in the summer 2000, the spectrum auctions in Europe and the emergence of other possible disruptive wireless technologies. Complexity and convergence are two central issues. The increased complexity of the technology creates disruption because development of UMTS technology requires huge resources; and the convergence between wireless technologies and the fixed net has potentially created even more disrupters.

The complexity of making a mobile phone in the growth phase of the technological life cycle is said to have increased 20-30 fold in each cycle. The increased complexity from the 1G to 2G required a large R&D effort, which mainly could be managed by the larger firms. MNCs entered the promising market and other firms formed alliances and cooperated in the early stages of the technology. Development of 3G handsets – let alone the equipment for 3G infrastructure - requires

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[16] In 1999 the International Telecommunications Union approved a global industry 'standard' for 3G called International Mobile Telecommunications 2000, which specify key requirements (e.g. speed, backward compatibility etc.) for 3G services.

huge R&D resources, which has led the big players to form joint development consortia. It is apparently not sufficient to be a big player in the early phase of this potential technological life cycle. Siemens and Motorola are collaborating on the development of Siemens 3G terminals using Motorola platform technology. Sony and Ericsson have founded a joint venture developing 3G handsets, Toshiba and Mitsubishi have formed an alliance, as also has the case for NEC and Matsushita (Panasonic).

In North Jutland the *density* of the cluster had increased during 1999-2000 and in the late 2000 there was approximately 28 firms employing nearly 4,200 persons, which was about half of the total ICT employment in the region. Several firms were doing GSM development and the cluster became significantly denser compared to the peak of the 1G cycle. But compared to the most outstanding regional concentrations or clusters, such as Silicon Valley, Southern Sweden, Southern Finland, Munich and Cambridge, it was still sparse. The following firms in the cluster were said to perform R&D in UMTS in late 2000: L.M. Ericsson (125 employees), Siemens (350), Maxon (105), Shima (60) and Condat (20). Today the picture has changed; Maxon is on 2G+, while Shima has been closed down. Ericsson has closed its UMTS development in North Jutland and Siemens has downsized its R&D staff from 350 to 250 during 2001-2002. Development of the basic 3G technologies does not appear to take place in the cluster to the same extent (in relative terms), as was the case in the initial GSM phase ten years ago. The crisis in the telecommunication industry and the increased complexity has made the players focus their R&D in larger units and form alliances. However the high complexity and the demand for an increased number of functionalities of the UMTS handsets open new opportunities for specialisation. The demand for new functionalities and features of the 3G technologies are potentially disrupting for 2G, but also brings in other disrupters.

The evolution of the mobile communication technology has lead to convergence between different ICT technologies. The mobile device and the wireless net are converging with the fixed net. The transmission of speech, text, pictures, etc. will be in focus. With the explosive development in data transmission and Internet access on the fixed net, there is an increasing demand for Internet access and data availability everywhere and all times. Although there is convergence, there still is difference between the mobile Internet and wireless access to the fixed Internet.

One of the major driving forces behind 3G is the 'killer' demand for data access on the move. There seems to be a huge demand for the combination of mobility and communication, which provides access to data and other corporate, commercial and communications services. Another driving force are crowded 2G networks, which especially in Japan has made a push for 3G. This has lead to an adoption of a preliminary 3G network not fully compatible with W-CDMA, forcing producers to make handsets, which cannot be used outside Japan. But the role of 3G is not seen merely as satisfying a growing demand for voice communication. The planned revenue and the potential disruption is rooted in data communication. However, other technologies are also available in that field. The two 3G standards UMTS and CDMA2000 can therefore be disrupted by other technologies capable of creating wireless access to the Internet.

At present there are five incompatible systems, such as W-CDMA, CDMA-2000, TD-CDMA (see http://www.imt-2000.org). UMTS is based on W-CDMA. The original idea of IMT-2000 was to create compatibility, but it could not be realised.

5.4 Is '4G' a major opportunity?

The massive investments required to build the coming 3G infrastructure paired with the present deep financial problems of the telecommunications sector in general (the equipment hardware industry as well as in telecommunications services) has increased the focus on what is coming next in the horizon. Usually 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 Mb/s and in operation in, say, 2010. There is however a certain ambivalence prevalent in the terminology at present. 'Premature' versions of 4G are much closer – in fact already available.

This potential disrupter is Wireless Local Area Networks, WLAN. This is a technology that makes short distance high-speed wireless Internet access possible. It is access to the 'usual' wired Internet – the mobile Internet is yet another field. The dominant emerging WLAN standard is the US IEEE 802.11, which so far appears to have out-competed the European ETSI standard of HyperLAN2. The WLAN 802.11b solution is already at the market under the nickname of Wi-Fi[17], which operates in the 2.4 GHz band and can offer speed up to 11 Mb/s within distances up to 100-130 m.

Given that 3G at best can offer data transmission in the area of 300-400 Kb/s within, say, 2-3 years, WLAN based solutions may seem very attractive even in the short run. The users will have to move to 'hot-spots' in the terrain - at hotels, airports, railway stations, cafés, petrol stations, etc. – to be able to reach the Internet, but then at speeds that far exceed present high-speed access solutions (DSL or cable TV modem based) at, say, 512 Kb/s. Instead of waiting at the 3G visions, users may demand a kind of 'surrogate 4G' solution where they will have to move in the terrain with their laptop PCs (or PDAs) *and* mobile phones. The latter may eventually be needed only as an encrypted access device to get access to the 'real' Internet through a laptop PC. Such a solution requires an infrastructure of hot-spots in the terrain.

Given that the US is lagging seriously behind the European mobile telecom infrastructure – with severe implications for the US mobile hardware industry - there are very strong incentives in the US market to promote a decentralised WLAN based wireless Internet access solution. The latter should be conceived as a supplement to the ordinary wired telecom infrastructure.[18] On this background there is a rapid process of technological change going on at present. A whole family of IEEE 802.11x solutions are popping up.[19] 802.11a is thus operating in the 5 GHz band at speeds potentially up to 54 Mb/s, although 'only' around 25 Mb/s at present. The disadvantage of the 802.11a is that it is not backward compatible to 802.11b and has a smaller range, but solutions to this problem are emerging.

WLAN is, opposite to UMTS, using unlicensed spectrum and is highly deregulated[20]. One of the attractions is the possibility to build up small range high-speed wireless networks for low cost and avoiding the problem of carriers controlling the 'last mile'. WLAN solutions have existed for a few years and are growing fast. It is being hyped in US and can be classified in two groups: private networks not open to the public and public networks with access for users that pay some sort of fee. At the private network end many universities have adopted WLAN, thus providing Internet access

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[17] Short for wireless fidelity

[18] Wi-Fi network starts with a DSL or other high-speed connection to the wired infrastructure. The connection is then linked with an access point allowing wireless access to the Internet by a WLAN card in the computer.

[19] See e.g. Gupta, P. "WLAN: Digesting the 802.11 alphabet soup", *CNETAsia* Electronic Newsletter 27 May 2002.

[20] WLAN 802.11b uses the 2.4 GHz band, which also is used by microwave ovens, DECT phones, Bluetooth etc.

access around campus. At the cooperate level there also are many users, but they are more concerned with security issues. Many private consumers have installed WLANs in their homes[21] to avoid cableing and some allow others to use their connection in neighbourhood-shared access or in 'freenet', being a grassroots initiative in providing hotspots with free Internet access, which especially is being built in the densely populated areas.

The public hotspots provided at hotels, cafés, airports, coffee shops etc. are giving rise to the emergence of Wireless Internet Service Providers, WISPs, creating network of hotspots and thereby becoming carriers of wireless Internet access. They allow users access by signing up and paying a fee. The public hotspots are organised as independent hotspots at a single location, such as hotels and airports or in a system of hotspots provided by a WISP. Both types are demanding a fee for access, but there is not often roaming between the independent public and WISP hotspots or even between the WISP networks. The WISPs are expanding their networks, especially in the US, and a few are trying to build 'national networks', but they still only cover small areas.

The private hotspots seems to be both economic and technical feasible although there still are some problems with security, the public hotspots are technical feasible, but still needs to be proven economic feasible.[22] The producers of WLAN equipment Intel, IBM, Lucent, Cisco etc. are pushing WLAN along with the WISPs, who are trying to make money on wireless data access and thereby 'steal' the mobile data communications marked before the rollout of 3G.

Where the incumbent carriers in fixed telephony, was challenged by entrant mobile carriers, the latter are now potentially challenged by the WISPs. But there are advantages and disadvantages with 3G as well as WLAN solutions. To summon a few, WLAN has higher speed, but is limited to hotspots, while the mobile networks are much slower but have much better coverage. The mobile networks allow the user to be moving. Both networks have conflicting standards. WLAN is limited to data transmission and has security problems, while the mobile phones have small screens. WLAN and the mobile networks have different price structures and both seem to need a 'killer business plan'. The WLAN solutions are up and running while 3G networks are at their very early stage in Japan and hardly existing in Europe and the US.

The sparse coverage and lack of roaming for WLAN can evidently could benefit from extensive geographical coverage of the mobile carriers, their strong customer base, roaming facilities, large-scale network management etc. (see e.g. Forrester 2001). On the other hand, the mobile carriers cannot neglect the WLAN technologies with their appealing speed. So there appear to be an evident potential for combinations of the two types of solutions. The flourishing field of WLAN has until now not received the same kind of media hype as the evolution of 3G in Japan and in Europe. But given the relative weakness of the US in mobile communications, it is of no surprise that the US media is focusing considerably more at WLAN solutions at present.

The potential disruptive effects of the WLAN technology vis-à-vis 3G may turn out to be a potential opportunity for the NorCOM cluster. Given that development of 3G handsets has been organised by the large telecom MNCs in pair wise alliances, this is a field very difficult to enter – at least in the initial phase of the 3G technology life cycle. The risk of 3G becoming a major failure cannot be neglected in light of the heavy financial burden the 3G infrastructure is causing for the

[21] The firms seem to favour the faster and more expensive 802.11a, while home WLANs usually are of the 802.11b type.

mobile telecom carriers. This is the basic background for the present true uncertainty about the future infrastructure: will 3G or WLAN solutions win? Or will they co-exist as true complements?

6 What policy may be able to do – and what not?

The uncertainties described above are of a global character. Although the institutional set-ups differ between the main group of players in Europe, the US and Japan, they are at present characterised by a very open ended situations, where quite different outcomes all may have some degree of probability. The relevance of policy measures and/or coordination between groups of actors may be of most relevance in exactly the very uncertain phase between two technological life cycles. The emergence and very fast growth the 1G and 2G mobile telephone industry in initially the Nordic countries followed by several continental European countries may to a considerable extent attributed to the standardisation initiatives performed by first the Nordic PTTs, then the EU created ETSI standardisation body.[23] Both efforts were due to visionary telecom regulators and (initially) incumbent monopoly wireless carriers.

This path to standardisation is often nicknamed the Nordic or continental European way, as opposed to the US approach, often characterised by a decentralised, if not anarchistic, bottom-up dominated procedure. The latter has been very successfully applied in the case of the Internet, where the process has been dominated by US actors, which has led to a US lead in the equipment industry as well as the emerging e-business industry, as analysed fairly detailed by Mowery and Simcoe (2001) and Kenney (2002).[24] The Nordic and European experience, so far at least, have fostered a common understanding of the significance of international coordination efforts ex ante. But the general crisis in the telecom service industry as well as among the equipment vendors from 2000 coupled with the huge rents that some of the major European governments have extracted from the coming 3G service providers in the auctions for 3G licences has caused a significantly higher degree of uncertainty in the transfer from the 2G life cycle to 3G. The outcomes are very difficult to predict, but they are on the other hand deeply dependent on actions taken by the major actors.

The outer poles of the future scenarios may be represented by:

1. 3G systems may dominate the mobile communications networks with WLAN solutions as a complementary service basically controlled by the incumbent mobile carriers.
2. 3G may prove to be a new 'Titanic' in Europe, if not Japan, because the US telecom industry may strike back by not adopting a 3G system at any large scale, but exploit the 2.5G options and combine them with the evolving opportunities offered by more decentralized WLAN experiments.[25]

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[22] One of WISPs, MobileStar Networks, who provided WLAN at the US Starbucks coffee shops filed for bankruptcy and was acquired by the Deutche Telekom owned mobile operator VoiceStream.

[23] Surveyed in detail by Gessler (2002).

[24] The lack of US dominance in the wireless industry is analysed by West (2000; 2002).

[25] At the moment of writing mayor US players - from Intel via IBM to wireless carriers such as AT&T Wireless, Verizon and Singular – are trying to set up a joint initiative, Project Rainbow, which in effect is an effort to create an industry standard, that will make it possible to move around and tap into a large share of the fast growing amount of hot-spots. This illustrates the US way of letting a de facto industry standard emerge without ex ante regulation from e.g. the FCC. As also a characteristic US feature, Motorola is trying to put forward an alternative solution.

Given such fundamental uncertainties it may prove relevant for a region involved in these technologies to put forward field experiments with the patterns of telecommunications services seen from a user perspective, firms, government agencies at all levels as well as private consumers. To organise such efforts it appears a key point to involve various experiments with the telecom infrastructure. The aim can be to be prepared for different future trajectories, if not to influence these outright. Even small regions may eventually influence the future development abroad if they may use their potential institutional advantages in terms of organising field experiments that may be visible internationally. An argument for public financing and engagement in research is that uncertainty related to knowledge production may result in under-investment in this activity (Nelson 1959; Arrow 1971). Another argument for support to a field experiment is that innovation is an interactive process. The interaction between suppliers, customers and knowledge institutions is a necessary condition for a successful innovation (Lundvall 2002).

In the case of North Jutland such options may be argued to be present, if the necessary consensus could be established. This region was in 1999 appointed as one of two Danish 'IT Lighthouses', or as the so-called Digital North Denmark (DDN). The national government did allocate approximately €25m and another €50m has been added by local government organisations (municipalities and the North Jutland County) as well as private firms, not restricted to be local.

The IT Lighthouse has been divided into four fields, of which the local IT infrastructure is one. A series of nearly 90 IT projects have been started during 2000-2003. Under the label of North Jutland Netforum, an Aalborg University group is collaborating with the largest IT service firm in the region, KMD, and a small group of municipalities in order to design local optical fibre based network solutions, which will bring 'true broadband' to local government organisations as well as to private firms and consumers. Given that how to organise this infrastructure – and not least the 'last mile' problem - still is one of the fundamental barriers for diffusion of IT in general, such experiments are of considerable importance in their own right.

However, the infrastructure projects of the IT Lighthouse open unique opportunities of creating field experiments with an optical fibre based local infrastructure that *also* contains extensive possibilities for WLAN access – i.e. field experiments which has been labelled 'surrogate 4G' above. The opportunity for the entire region is that the present growing pessimism, caused by troubles of the GSM developers to get a foothold in the UMTS world, could be changed with a vision focusing of combining some of the existing knowledge assets of the region and the country at large.[26] Two research teams at Aalborg University have proposed a joint Centre for Tele Infrastructure (CTIF) – joining the CPK research competence in wireless technologies with the wired infrastructure group.

Taking into account that a considerable competence has been developed in the NorCOM cluster in developing 2G, 2.5G and – at least among some of the firms – competence in various parts of 3G technology as well as a significant competence has been developed in the Bluetooth field, itself an industry standard for data transmission over very short distances, there are several important points of departure, which may form an ideal background for coming at the forefront in wireless-to-wired data communications field – i.e. to become involved as a visible player in the early stages

[26] For details of this vision see the "Vision Nordstjernen" report (NOVI 2002) made by a group of university researchers and managers from the local ICT industry. Two of authors of the present paper were secretaries for the project.

of a new technological life cycle.[27] Not necessarily because of major technological breakthroughs, but *through the capability as a region* to combine unique field experiments in the field of wired and wireless telecom convergence with competence among several NorCOM firms to find various footholds in the field in the early stage, and especially to be placed as a 'core player' in the international standardisation efforts through documented user experiments. If the field experiments may prove successful the rumours could spread internationally, create visibility and attract some of the big global players. Echoes of the vision may be heard internationally – as happened successfully during the recent peak of the GSM cycle, but momentum has been lost at present.

Whether such a vision can find the necessary support nationally and locally remains to be seen. The policy challenge is to perform the act of combining efforts at experimenting with the consumption structure (i.e. the telecom infrastructure), supporting the basic university research in the field of convergence between wireless and wired telecom (i.e. creation of the CTIF centre) and interacting with the local industry. This has been proposed as a so-called 'IT Lighthouse 2' programme.

Policies at the regional level, and in the Danish case at the national level neither, cannot by their very nature *create* competitiveness among local high tech firms, such as those in the NorCOM cluster. The history of the latter has never proved to be the outcome of any 'grand plan' designed ex ante. However some of the components behind the emergence of this cluster were definitely the outcome of deliberate policy efforts and long-term struggles, such as the establishment and further consolidation of Aalborg University in 1974 and the science park NOVI in 1989. A 'grand design' of the future of the NorCOM cluster cannot be planned for the same obvious reasons. But the probability to find luck is at least sometimes increased for the prepared mind. Social experimentation with different solutions may be key activities, if indeed the general public is prepared to take risks and accept that taxpayer's money may be lost, but not necessarily wasted, through such a process. These are the 'rules of the game' for policy experiments in an evolutionary setting.

[27] At the national level it is worth noting that there is a parallel cluster of optical communications equipment firms in the Copenhagen region as well as a strong competence at the Technical University of Denmark, DTU, in Copenhagen. These two clusters and their knowledge background at the respective two large technical universities are basically complementary, which is an ideal background for national co-operative R&D programmes in this field.

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8 Appendix

Table A1 Data of the companies located in the North Jutland Communications Cluster

Firm	Activity	Employees	Establ.	Owner
Analog Devices	Wireless systems applications (chipsets for mobile communications)	25 (2002)	1997	Analog Devices (Boston, US)
BD-Consult	Production & development of specialised mobile comm. equip.	16 (2002)	1988	Founder (DK)
Bluetags	Bluetooth applications	8 (2002)	2000	Founder (DK)
CPK	Research centre	60 (2002)	1993	Sponsored by Aalborg University, research councils, EU and industry
CSR - Cambridge Silicon Radio	Design of single-chip radio devices. Applications for Bluetooth.	6 (2001)	2001	CSR, (Cambridge, UK)
Danphone Communications Systems	Development of land mobile (closed) radio communication systems	11 (1999)	1990	Eltomatic (DK)
Digianswer	Development of Bluetooth technology	83 (2002)	1986	Motorola (US) majority. Founder (DK) 1/6
Danish Wireless Design (DWD) A/S	Development of GSM/GPRS equipment	48 (2002)	1999	Infineon (Munich, GER)
Eurocom Industries	Production & development of maritime comm. & navigation equipment (GMDSS/VHF) & satcom. equipment	Approx. 260 (2001)	1992 (1948)	SAIT-Radio Holland (BEL-NLD) & STN Atlas (GER)
End-2-End	Wirefree Application Infrastructure Provider (WAIP).	50 (2002)	2000	Pre-tel Wireless (London, UK)
Ericsson	Software development for UTMS, GSM, GPRS and Bluetooth	15 (2002)	1997 (1993)	LM Ericsson (SWE)
ETI	Telecommunication analysis equipment	86 (2002)	1985	Private owned
Flextronics	Production of mobile terminals (GSM/GPRS, PCS1900)	1100 (2002)	2000	Flextronics (US)
Force Electronics	Production of satellite TV receiver equipment	18 (2001)	1989	Satellitt Companiet (Oslo, NO)
Futaque	Development of satellite TV receivers	25 (2001)	2001	NOVI A/S, Erhvervsinvest Nord (DK)
GateHouse	System software and data protocols for satellite and radio communications	23 (2002)	1992	Founders and employees
GlobeSat	Production & development of satellite disks	3 (1999)	1993	Founder (DK)
LH Technologies Denmark ApS	Development, manufacturing and marketing of electronics for agriculture	70 (2002)	1992 (1976)	Spraying Systems Co. (Illinois, US)
LH COMLOG A/S	Systems for communication and logistics in the transport business	25 (2002)	1998 (1992)	Founder (DK)
Maxon	Development of GSM/GPRS and UMTS equipment	130 (2002)	1991 (1987)	Maxon Telecom Co. (KOR)
M-tec	Equipment for GPS based road pricing	20 (2001)	1998	Founder (DK)
Niros Telecommunications	Development of professional land mobile radio equipment (LMR)	8 (2002)	1985	Private owned
Nokia	Software for WAP and UMTS	20 (2002)	1999	Nokia (FIN)
NOVI	Science Park at Aalborg University	43 firms (8 from this table) (2002)	1989	Major Danish institutional investors and as minor shareholders regional authorities
On-Air	Software for real-time end-to-end video streaming solutions to cellular and wireless products	7 (2002)	2001	A/S Dansk Erhvervsinvestering and IPM Management A/S
Partner Voxtream	Development of telecommunications equipment (routers etc.)	10 (2002)	1999	NatWest Equity Partners (UK) and EHP Toftlund A/S (DK)

Table A1 Data of the companies located in the North Jutland Communications Cluster (continued.)

Firm	Activity	Employees	Establ.	Owner
Penell	Bluetooth. GSM-modems.	20 (2002)	1991	RTX Telecom A/S
RF Micro Devices, Design Centre Denmark	Design of radio frequency chips	3 (2001)	2000	RF Micro Devices, North Carolina (US)
Rohde & Schwarz Technology Centre A/S	Development of test equipment for UMTS and Bluetooth	39 (2002)	1993	Rohde & Schwarz GmbH & Co. KG (Munich, GER)
RTX Telecom A/S	Development of DECT, Bluetooth, CDMA and UMTS equipment	230 (2002)	1993	Founders (DK) 46%, National Semiconductors (US)
S-Card	Production of chip cards for telecom (e.g. SIM cards)	20 (2002)	1991	Founder (DK)
Siemens Mobile Phones A/S	Development of GSM/GPRS and UMTS equipment	200 (2002)	2000	Siemens (GER)
Simrad	Production & development of maritime navigation and communication equip. (GPS/VHF)	120 (2002)	1994 (1977)	Simrad (NOR)
Sonofon	Mobile communications. Service provider	953 (2001)	1991	Bell South (USA) 47,5% and Telenor (NOR) 52,5%
SpaceCom	Production & development of satellite communications equipment	16 (2001)	1989	Founder (DK)
STMicroelectronics	Development of protocol software for GSM/GPRS and UMTS chips	10 (2002)	2001	STMicroelectronics (FRA, ITA)
TDC	Service provider. Mobile and fixed net	45 (2002) 18,988 (total number of employees in TDC)	1990	Ameritech (US)
Telital R&D Denmark	Development of GSM/GPRS and UMTS equipment	65 (2002)	1998 (1985)	Telital (ITA)
Texas Instruments	Development of GSM and UMTS equipment	108 (2002)	1996	Texas Instruments (US)
TTPCom	Software for GSM/GPRS and UMTS	16 (2001)	2001	TTPCom (Cambridge, UK)
WirTek	Wireless software technologies	15 (2002)	2001	Founders
Aalborg University (AAU)	Technical, social science & humanities faculties	13,000 students & 1,700 staff (2001)	1974	Government

Note: Updated 28-08-02.
Source: The homepage of the NorCOM cluster (http://www.norcom.dk)

Danish **R**esearch **U**nit for **I**ndustrial **D**ynamics

The Research Programme

The DRUID-research programme is organised in 3 different research themes:

- The firm as a learning organisation
- Competence building and inter-firm dynamics
- The learning economy and the competitiveness of systems of innovation

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

Theme A: The firm as a learning organisation

The theoretical perspective confronts and combines the resource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human resources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

Theme B: Competence building and inter-firm dynamics

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.

The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

Theme C: The learning economy and the competitiveness of systems of innovation.

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

The main empirical and policy issues are related to changes in the local dimensions of innovation and learning. What remains of the relative autonomy of national systems of innovation? Is there a tendency towards convergence or divergence in the specialisation in trade, production, innovation and in the knowledge base itself when we compare regions and nations?

The Ph.D.-programme

There are at present more than 10 Ph.D.-students working in close connection to the DRUID research programme. DRUID organises regularly specific Ph.D-activities such as workshops, seminars and courses, often in a co-operation with other Danish or international institutes. Also important is the role of DRUID as an environment which stimulates the Ph.D.-students to become creative and effective. This involves several elements:

- access to the international network in the form of visiting fellows and visits at the sister institutions
- participation in research projects
- access to supervision of theses
- access to databases

Each year DRUID welcomes a limited number of foreign Ph.D.-students who wants to work on subjects and project close to the core of the DRUID-research programme.

External projects

DRUID-members are involved in projects with external support. One major project which covers several of the elements of the research programme is DISKO; a comparative analysis of the Danish Innovation System; and there are several projects involving international co-operation within EU's 4th Framework Programme. DRUID is open to host other projects as far as they fall within its research profile. Special attention is given to the communication of research results from such projects to a wide set of social actors and policy makers.

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