Clusters in Transition: Cluster decline and resilience

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1. Introduction

Regional clusters have gained much attention by scholars and practitioners during the last 20 years. One key feature of regional clusters is that once they have emerged, they appear to be very resilient to chocks and often continue to exist for many years. However, sometimes technologies and market conditions suddenly shift; firms close down, entry of new firms stops, highly skilled employees leave and clusters decline. Firm exit might release a wave of creative employees and diffuse knowledge in the cluster (Buenstorf and Fornahl, 2009). But firm exit also reduces interaction, agglomerations economics and variety (Hoetker and Agarwal, 2007). Successful clusters often overcome several major disruptions during its evolution that might have led to decline, while less resilient clusters decline. This process has been given less attention in the literature. The purpose of the paper is to study the process of decline and how the concept of resilience can explain cluster decline.

The population concept of resilience can be quite useful in providing a conceptualization of the shift from a normal well-functioning cluster to a declining cluster. Walker et al. (2004) defines resilience as: ”the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain the essentially the same function, structure, identity and feedbacks (p. 5)”. Resilience is the amount of disruption and stress a system can take or adapt to and still function before it starts to break down. It is also the capability to adapt and change in response to disruption and still retain the same identity and knowledge base. This definition implies that there is both a quantitative and a qualitative part of resilience, which has made it difficult to investigate empirically and apply to evolution of regional economic systems (see e.g. Simmie and Martin, 2010; Holm and Østergaard, 2011; Martin and Sunley, 2011). The understanding of resilience differs qualitatively depending on the level of aggregation, such as firm level, cluster, region, industry and country. Furthermore, resilience draws on four different capabilities that all refers to the possible outcome of an external chock: the ability to withstand external chocks, the ability to make small changes, the ability to make large changes and the ability to completely transform itself. The latter capability is closely related to the capability of the region since it would imply that the cluster transforms its identity, technologies and products which challenge most definitions of a cluster consisting of firms with a certain common knowledge base. Thus it is necessary to look at both the internal and external context when analyzing the decline of clusters.

Clusters often have a high level of resilience. The positive factors and processes that sustain clusters also make it resilient. When a company experiences a crisis and downsizes or closes down, the laid-off employees often are

able to get a job in another firm in the cluster, spinoffs emerge or new firms enter the cluster since they can get entire teams of highly-skilled labor. Thereby the knowledge and skills are kept in the region and sometimes the cluster might even grow as a result of a company's decline like the ICT cluster in Jena, Germany, that grew through spinoff companies from the declining large B2C firm Intershop (Buenstorf and Fornahl, 2009). As a result the cluster and employment seems to be fairly stable to internal and external events.

However, if the cluster's resilience is weakened by various internal factors then negative external events may become disastrous and the cluster starts to decline. The function of the cluster then breaks down, the knowledge base shrinks when companies close down and high skilled employees leave the cluster and get a job in other industries or regions. When the number of firms and employees declines, it also reduces the chances for future spinoffs, the possibilities for interaction, and agglomeration economies. The firms' organizational template and some of the firm's knowledge is lost, since the knowledge of the firm is more than the sum of the employees' knowledge. Although the knowledge might live on in employees, the exit of firms limits the diffusion of knowledge and leads to a loss of knowledge, interaction, learning through observation, and organizational routines (Hoetker and Agarwal, 2007).

This paper intends to investigate the process of cluster decline and the role of cluster resilience in this process. The conclusions we derive are based on a case study of wireless communication cluster in North Jutland, Denmark. The cluster emerged in the 1980s and it grew fast in terms of number of firms and employment during the 1990s along with the rapid growth of mobile communications industry. In the early 2000s the cluster faced several disruptions in terms of changes in technologies and closure of mobile phone manufacturing firms due to the overall turbulent changes in the industry. The number of firm exits increased, but the employment of highly skilled engineers remained fairly stable since other firms hired laid-off engineers and new firms entered the cluster. A few years later, the entry of new firms stopped while the exits continued and this process of decline was enhanced in 2009 when the two largest R&D firms in the mobile phone part of the cluster closed down within a few months.

The paper is organized in the following structure. Theories of cluster resilience and decline are presented in Section 2. Section 3 describes the methodology of the paper. The case of the wireless communication cluster is described in section 4. The discussion and conclusions follow in section 5 and 6 respectively.

2. Theories of cluster decline and resilience

The last two decades of research have revealed that clusters are different in terms of size, geography, age, knowledge base and breadth and depth of the value chain. An often used definition of clusters is provided by Porter (1998):" 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)". This definition is, however, imprecise in delimiting the boundaries of the cluster concerning how the companies are interconnected and how the commonalities and complementarities should be perceived (Martin and Sunley, 2003). It is apparent that the firms need to be linked more than just through the same geographical location and labor market. They must be coherent with activities within a limited part of an industry or industries and the same technological knowledge

base. Therefore, they draw on a common pool of labor with knowledge and skills from the same technological knowledge base. The cluster's identity is based on these factors e.g. a software cluster or a wireless communications cluster.

2.1. Cluster resilience

Martin (2011) identifies three interpretations of resilience; engineering, ecological and adaptive resilience. Engineering resilience is the ability of the system to return to its pre-disruption level. Ecological resilience is the scale of disruption a system can absorb before it breaks down or move to another stable state. Adaptive resilience is the ability to reorganize to minimize the impact of a disruption. He also identifies four dimensions of regional resilience: resistance, renewal, recovery and re-orientation. These dimensions show how regions response to external disruption. Reflecting this concept of resilience in the context of a cluster, we have to keep in mind that a cluster consists of many firms and organizations that have different strategies. Their interpretation of a potential threat and reaction to this depend on the firms' existing technological capabilities. The only way the cluster can change is through the actions of individuals, firms and other organizations and they react sometimes very differently. However, the changes appear to be more than the combined changes of these because of the interconnections between the firms and that a firm's action affects the possibilities of others. Furthermore, these internal actors are also to a large extent affected by external changes outside the cluster. The resilience concepts often focus solely on internal factors, but firms have outside links that affect the cluster resilience. Sometimes these interactions are positive for firms and the cluster, when they are able to receive information, knowledge and resources from the outside, however, it can also be negative, when multinational companies decide to close down subsidiaries or e.g. enforce a company culture that limits local interaction.

We argue that cluster resilience is an adaptive capability that allows it to make changes to overcome internal and external disturbance and still function with its identity. The capability consists of the ability to withstand external chocks, the ability to make small changes, the ability to make large changes and the ability to completely transform itself. Cluster resilience, like regional resilience, could have different dimensions. However, the re-orientation of a cluster would mean that the cluster transform itself completely. There are some examples of this transformation, such as the semiconductor industry in Silicon Valley in the 1980s, the minicomputers in Route 128 in late 1980s early 1990s or the High Tech cluster in Cambridge, UK. It is though important to note that this ability is related to the capability of the region that continuously adds new activities to the cluster when the old ones seem to stagnate.

2.2. Cluster decline

The cluster literature has focused on the positive effects that lead to clustering, such as the Marshallian externalities, explaining that firms benefit from co-location in a cluster through economies of specialization, economies of labor pooling and localized knowledge spillovers. However, most of these positive factors also have a negative side. When many related firms are co-located, the congestion effects raise prices and wages. The labor pooling increases competition for specific skills and thus raises wages. It is also easier for employees to change jobs within a cluster, which means that companies can lose valuable knowledge to potential competitors. In addition the localized knowledge spillovers also lead to a loss of information that could weaken firms' performance. The attraction of other firms to the cluster might therefore hamper the incumbent firms' growth (Falck et al., 2011), and this also applies to the startups including the spinoffs. Sorensen and Audia (2000) find

both a higher startup rate and a higher exit rate in clusters, thus the churn is higher, which indicates the existence of negative externalities in a cluster. Similarly, Klepper (2010) finds that it is mainly spinoffs from better companies that performed well and helped building the semiconductor cluster in Silicon Valley and automobile cluster in Detroit while other types of entry performed worse, which indicates that positive externalities from agglomeration were not very strong. Furthermore, the factors and processes that were an advantage for the cluster sometimes end up being a reason for decline (Martin and Sunley, 2006).

It is difficult to point to single explanations for the decline of clusters, since the changes in a cluster could come from the interaction between several factors inside and outside the cluster. As a result it is necessary to look both at the micro dynamics of the cluster e.g. new firm formation and structural changes, such as technological change and market demand. Porter (1998) also states that causes for decline can be both internal and external. Internal causes stem from cluster itself as it forms rigidities that diminish productivity and innovation. External causes originate from developments or discontinuities in external environments, such as technological discontinuities or changes in demand.

Belussi (2006) explains that the emergence of negative externalities such as congestion, cut-throat competition in final markets, increased prices for inputs and property, too much embeddedness of the institutional context, and locking-in into obsolete and/or ineffective innovation and learning system might lead to cluster decline. Enright (2001) argues that clusters fail when their strengths such as localized routines, geographically impacted information, and ties between local firms and institutions become their weaknesses. According to Enright, five basic failure modes can be observed. First of all, falling demands for a cluster's products can harm the cluster. Organizational obsolescence could dissolve clusters as small firms sometimes merge into one or a few firms. Cluster can also be displaced by similar clusters in other locations. The fourth mode is loss of cooperative relationships within cluster. Lastly, clusters can fail due to loss of dynamism through lock-in. According to Grabher (1993) lock-in consists of factors that diminish cluster's ability to recognize and make adjustments to changes in their environment. Grabher (1993) defined the failure of old industrial districts into three kinds of lock-ins. The first is a functional lock-in, which refers to hierarchical inter-firm relationships that hinder suppliers from developing critical functions such as marketing and R&D. Cognitive lock-in means that clustered firms share a common world view or mindset that makes them hard to respond to outside changes. Political lock-in concerns institutional effort to keep existing industry structures which might damage the development of creativity.

Despite the longevity of clusters, they are not static, but evolve over time. The technological knowledge base continuously evolves depending on the actions of the organization in the cluster and the changes in the industry and market. Disruptive technologies that change the underlying knowledge base for an industry can easily lead clusters to decline especially if the cluster firms are not able to move to the new technology or suffer from a technological or cognitive lock-in (Storper and Walker, 1989; Christensen, 1997; Dalum et al., 2005). The firms in a cluster might suffer from a technological group think that reduces the heterogeneity of knowledge in the cluster, which reduce the resilience and lead to decline.

2.3. New firm formation as a source of resilience

The importance of entrepreneurship in cluster evolution has been found in many recent empirical studies, such as the semiconductor industry in Silicon Valley (Klepper, 2010), automobile industry in Detroit (Klepper, 2010),

and tire industry in Akron (Buenstorf and Klepper, 2009). These demonstrate that spinoffs defined as firms established by entrepreneurs with experience from existing firms in the same industry drive cluster formation since spinoffs tend to locate close to the 'parent' companies and spinoffs perform better than other entrants (Buenstorf and Klepper, 2009; Dahl and Sorensen, 2009; Parwada, 2008; Sorensen and Audia, 2000).

Agarwal et al. (2004) found that spinoffs survive at a higher rate than any other types of entrants. Buenstorf and Klepper (2009) find that successful industry incumbents become training grounds for prospective entrepreneurs. In this way, relevant skills and knowledge are transferred from the incumbents to the new organizations, providing advantage to spinoffs compared to other entrants in the industry. Similarly, Dahl and Reichstein (2007) argue that spinoffs from surviving parents are more likely to survive than spinoffs from exiting parents and other start-ups. Spinoffs from exiting parents have even less likelihood to survive than other start-ups, implying that it is type of experience that is important rather than the level of experience.

New firm formation also has implications for cluster resilience. Holm and Østergaard (2011) find that the level of new firm formation has a positive impact on regional industrial resilience to changes in the business cycle. New firms often increase the heterogeneity of the knowledge base and bring variety to the cluster. Therefore, no entrants in the cluster mean that the diversity of knowledge and competences is decreasing, affecting the cluster's ability to renew itself (Menzel and Fornahl, 2010). The stop in entry also might lead to decline in the number of firms if the exit rate is persistent (Sorenson and Audia, 2000). Furthermore, some firms are better training grounds than others and make more spinoffs, while other companies never produce a single spinoff (Klepper, 2010). If the first type of company closes down, it could also mark the beginning of the decline of a cluster. Therefore, the level of new firm formation (especially spinoffs) seems to be either one of the main causes of cluster decline or a symptom of the beginning of the decline.

2.4. Multinational corporations (MNC)

Multinational corporations are often important participants of clusters. MNCs are increasingly basing their knowledge-intensive activities in clusters, "affecting both the nature and intertemporal evolution of local innovative activities" (Mudambi and Swift, 2012, p.1). The effect of MNCs in cluster decline and resilience depends on the motive for entering and staying in the cluster. In the literature, two main motivations for FDI can be identified. The first is the classic 'technology-exploiting' motivation, explaining that a company enters a location where it has technological superiority over the local rivals that can be exploited better by FDI than export (Dunning, 1979). The second motivation is 'technology-sourcing' (Fosfuri and Motta, 1999; Driffield and Love, 2003). Firms with this motive enter a market to access proprietary technology, hoping for 'reverse spillover' from technology leaders in the host country to the MNCs. In the empirical analysis of productivity spillover of FDI in the UK, Driffield and Love (2007) find that inward FDI motivated by 'technology-exploiting' rationale leads to positive spillover where as 'technology-sourcing' FDI did not have spillover effect on productivity. The explanation is that firms that are 'technology-exploiting' have superior technology compared to the local firms and therefore can introduce new technology to the host country. On the other hand, firms with 'technology-sourcing' motivations are typically technology laggards, which generate little technology transfer. De Propris and Driffield (2006) analyzed spillover effect of FDI on domestic firms and foreign-owned firms. They found that both firms in clusters gain significantly from FDI compared to the non-clustered firms. This suggests that there exist both positive spillover and 'reverse spillover' of FDI, to firms within clusters. However, foreign-owned firms are more footloose than indigenous firms. Foreign firms are more likely to restructure,

relocate, sell, and close down the units in economic downturn (Görg and Strobl, 2003; Bailey, 2003). Therefore, the effect of MNCs on cluster resilience is like a double-edged sword that these companies bring in resources to the cluster, but they might also quickly leave again.

3. Methodology

3.1. Data collection

The data on our case, the wireless communication cluster in North Jutland 1963-2011, was collected in the following ways. First of all, we started with archives from earlier studies on the emergence and development of the cluster (e.g. Dalum, 1995; Dahl et al., 2003). The list of all firms that have been active in the cluster until 2003 had been compiled by Dahl et al. (2003) with the founding and exit year (if any), the names of founders and their previous workplaces, and the main events in the history of the firma such as acquisition and bankruptcies. Then, we identified new entrants from 2003 and onwards by consulting cluster organization's archive on member companies and searching in the various online databases for newspaper articles, media reports and corporate information. After updating the list of firms, we identified the founders of the new companies and their former employers in similar ways, relying mainly on online corporate database, corporate websites, online network platforms and newspaper articles. Each firm has been researched thoroughly for main events including ownership change and closedown mainly on internet sources.

The next step was to collect data on the number of employees of each firm for the last two decades. The early employment data until 2002 came from earlier scholarly work on the Norcom cluster (Dalum, 1993, 1995, 1998; Dalum et al., 1999; Pedersen, 2001; Dalum et al., 2002). The numbers from 2002 and onwards are collected from diverse corporate databases, depending on the time periods that the firms existed. For the firms that still exist now, an online corporate database was used to track the number of employees up to five years back. We used a different corporate information archive to find the numbers for the firms that have already exited the cluster before 2011. Since not all firms are covered by those databases, newspaper articles and media reports were used additionally to find the numbers that are missing. When we finished this step, there were still some numbers lacking. Then, we took estimation by taking the average of the numbers before and after the missing period, assuming that the number of employee grew or decreased linearly.

The last part of our data includes a list of former Motorola and Texas Instruments employees who were laid off when the two firms exited the cluster in 2009 and their new workplace, including the location and the new job function. The data for the former Motorola employees came from one employee who kept track of where his colleagues found new jobs. He collected information directly from the colleagues or from an online network platform. The list of former TI employees was compiled by the authors by searching on the same online network platform. It is hard to find the accurate number of employees who were affected by the closure of the two companies as many employees changed job before the date of official exit. However, comparing the number of fired employees officially reported in the media and the number of employees we identified on our list, we can conclude that our data is rather complete. Furthermore, we have identified spinoffs established by former Motorola and TI employees after the company closure by searching on online media sources. Then, this list was double-checked with the data on new jobs of the former employees.

3.2. The genealogy of the cluster

The genealogy of the wireless communication cluster from 1963 to 2011 is created based on the collected data (see figure 1). This illustration summarizes the history of the cluster and shows the importance of spinoff activities in the development of the cluster. Fine arrows between firms show that one or more employees from existing firms established spinoff firms. Dotted arrows represent parent spinoffs where the founders or initial management have come from local firms. Bold arrows show change in the original structure of the company including acquisition by another firm and reconstruction after financial difficulties. Firms with dotted box have exited the cluster.

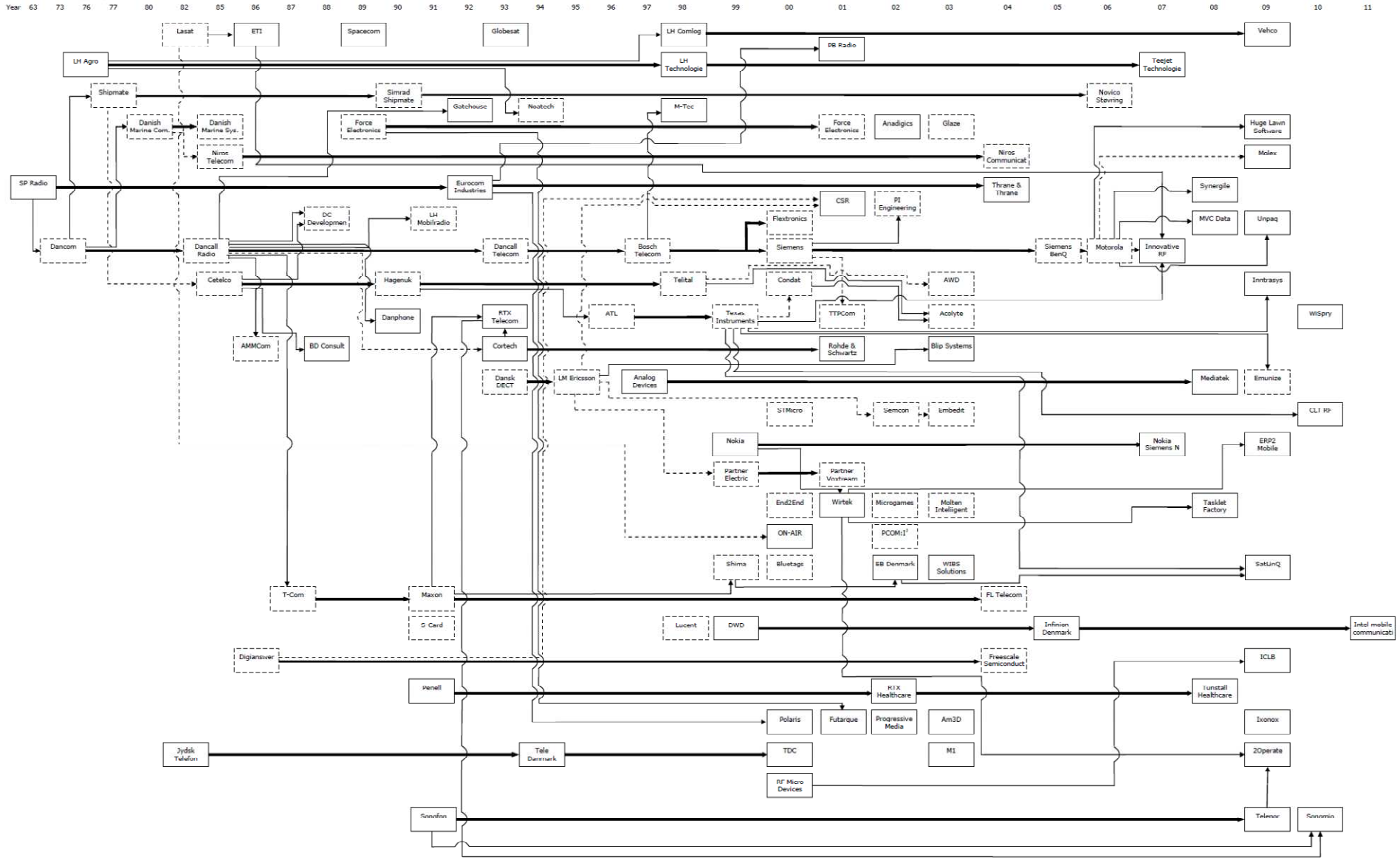
4. The case study: the wireless communication cluster in North Jutland (NORCOM)

The wireless communication cluster located in the region of North Jutland in Denmark includes firms in the field of maritime communication and navigation, telecom and land-based satellite communications equipment, and mobile and cordless communication. In 2011 it consists of 45 firms, 2300 employees, a university and a cluster association. The cluster started with one company which excelled in the field of maritime communication equipment in the 1960s and grew with spinoffs and other entrants that diversified gradually into the related areas of mobile communication and satellite equipments among others over the next four decades.

The cluster has experienced three periods of major external disruptions: 1) in 1988-92 following the shift of mobile communications standard from the Nordic NMT standard to the European GSM standard; 2) in 2000-3 when the mobile communications standards shifted to a world communications standard and the telecommunications industry was in turmoil following the 3G spectrum auctions and the dot-com crisis; 3) in 2007-9 during the financial crisis, the new shift in mobile communications standards and the introduction of Apples iPhone and Android smart phones. The cluster survived and even came out stronger after the first period of disruptions despite the leading firms went into financial trouble and were acquired by foreign MNCs. The cluster also survived the second period of disruptions, but also showed signs of decline as the number of firm exits increased. The cluster resilience was greatly reduced as the firms to a large extent were not able to move into the new mobile communications standard. In most recent period of disruptions the decline of the cluster intensified. The low resilience was further reduced when key firms exited and their employees left for other industries and regions. However, the cluster also experienced a wave of entry by small entrepreneurial spinoffs and parent firm start ups, but these have very few employees.

The next section provides an overview of the evolution of the number of firms and employees in the cluster, while the next three subsequent sections investigate how the disruptions affected the cluster, how the firms reacted in more detail, and how the resilience of the cluster changed over time.

Figure 1 The genealogy of the cluster



Source: Updated from the genealogical evolution figure in Dahl et al. (2003, p.20)

4.1. Overview of the cluster in decline

Figure 2 shows the change in the population and the entry and exit trend in the Norcom cluster. The number of firms had increased steadily until 2003 as there were very few exits but plenty of entries. Then, between 2004 and 2006, there was no entry at all while firms continued to exit. The cluster started to decline in 2004 and the number of firms dropped quite drastically. In 2008, the number of entry and exit equaled because entry started to grow. In 2009, the number of entry for a year peaked as 10 new firms were established. Although some firms exited in the same year, the total number of firms recovered to 45 due to the high increase in entry.

Figure 2 Entry and exit of firms in the cluster

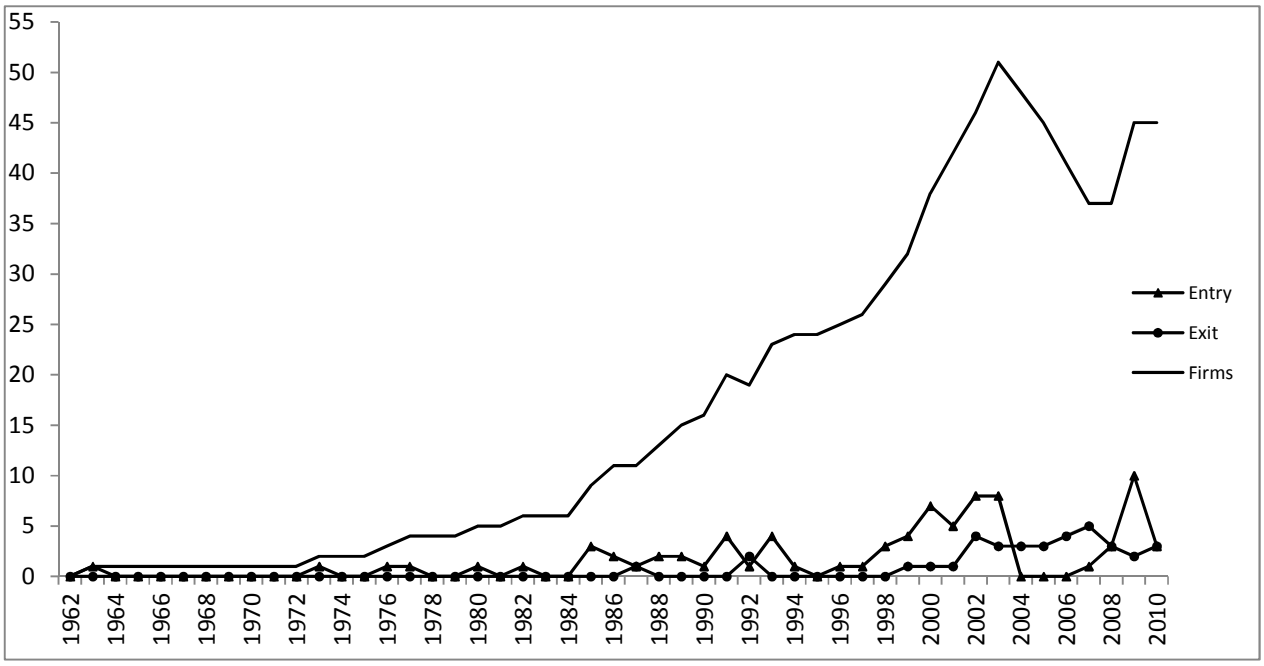
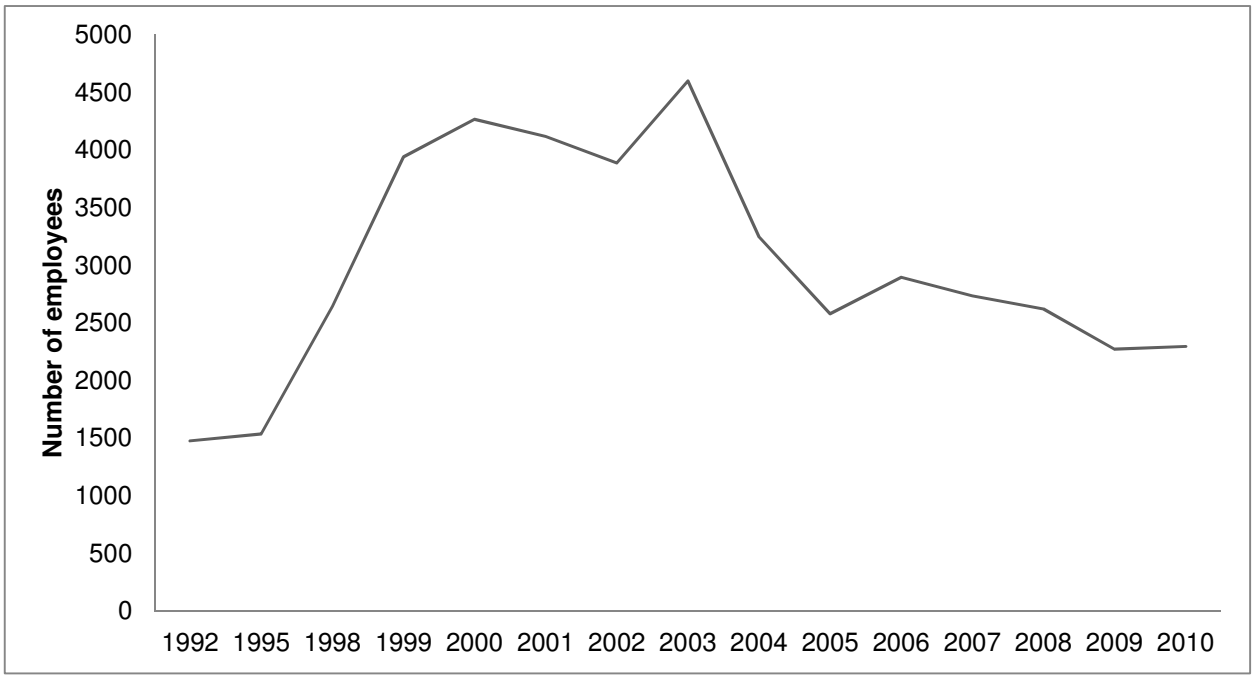


Figure 3 shows the change in the number of employees in the cluster over the last two decades. The declining trend is apparent from 2004 as it also is in terms of the number of firms. Following the dot-com crisis, the total employment decreased slightly from 2000 to 2002, but increased again in 2003. From 2003, the number had decreased quite drastically until 2005 as many firms downsized and exited in this period. Except the increase by 316 in 2006, the number had continued to decline until 2010, when the number increased merely by 24.

From the above analyses, we conclude that the cluster has been in a declining phase since 2003. First of all, the number of employees has been falling continuously since 2003 although the decline had slowed down since 2005 and the number of employees has been stable during the last couple of years. In terms of the number of firms in the cluster, it seems like a kind of renewal took place in 2009 as a relative high level of entry is observed after some years of very low entry. However, survival of these entrants and their influence on the cluster is rather questionable. The majority of the new firms in 2009 were founded by former Motorola and TI employees after the two firms exited the cluster.

Figure 3 Employment in the cluster



Among eight spinoffs, four of them have founders who have another regular job other than the start-up. These four founders demonstrate necessity-driven entrepreneurs, who founded consulting firms while they were between jobs. Moreover, the majority of the new firms have one or two employees which represent the founders themselves. After a couple of years of operation, most of them do not show growth in terms of employment. We also observe substantial employee migration from the cluster to other industries or to other regions in 2009 when Motorola and Texas Instruments closed down after a period of downsizing. The two companies played an important role in the cluster, since Motorola (former Dancall) was the seedbed of eight spinoffs and Texas Instruments had had a fast growth during the early 2000s. Only 27 percent of the former employees from the two companies stayed within the cluster with their new jobs. Considering that the two companies were R&D units and the former employees were mainly engineers, we conclude that the cluster lost its capacity to retain knowledge workers and therefore is in the declining phase. What is also raising concern is that new firm creation stopped totally in the period between 2004 and 2006. These three years of no entry have clearly contributed to the downturn, by not compensating for the continuous exits. Summing up, employee migration to other industries and regions, increased level of exit, and lack of entrepreneurship are the symptoms of the decline, but at the same time the cause of reduced resilience which will lead to further decline.

4.2. Disruptions and resilience of the cluster in its history

The emergence of the cluster (1960-80s)

The history of wireless communication cluster in North Jutland (named Norcom) started with the success of the leading producer of maritime communication equipment, S.P. Radio. S.P. Radio (established in Aalborg in 1942) produced consumer electronics until the early 1960s when the founder decided to produce radio communication equipment for maritime use for small and medium sized vessels. The company had huge success by diversifying into this area as there was almost no competition in the market and its equipment was technologically more advanced than those of the few competitors. A couple of successful local spinoffs have sprung up from S.P. Radio in the 1970s. In 1973, three engineers including the head of R&D from S.P. Radio established the first spinoff company, Dancom. Dancom also produced maritime communication equipment and competed with S.P. Radio in the same markets. A few years later, two engineers from Dancom started Shipmate which also produced radiophone for maritime use. In the 1980s, Shipmate developed a satellite navigation system which became one of the company's main products together with the radiophone.

In the 1980s, a range of the next generation spinoffs came from Dancom (restructured and renamed to Dancall Radio in 1983) and Shipmate. These companies diversified into a related area of personal mobile communication equipment which was led by the introduction of new technology – the common Nordic standard for mobile telephony (NMT). Inheriting capabilities within maritime radio communication from the parent companies, the spinoffs were well equipped for this diversification. One example of the next generation spinoffs is Cetelco that was established as a parent spinoff by Shipmate with the purpose of exploiting the promising business opportunity in mobile communications, the overlap between maritime communication technologies and mobile telecommunication technologies, and the possibility of economies of scale in production. Cetelco developed its first NMT phone in 1986 and began to produce mobile phones for several European and East Asian countries. At the end of the 1980s, there were 15 firms in the industry and the majority of the firms were spinoffs. However, the common European standard for mobile telephony (GSM) was introduced in the late 1980s and the leading producers of mobile phones competed to be the first one to develop a GSM phone. This posed a major threat to the cluster.

The first disruption (1998-1992) and the result (1990s)

The evolution of mobile communication technologies can be explained well by technological life-cycles (Dalum et al., 2005). Different generations of mobile communication technology (1G, 2G, 3G, and 4G) have life-cycles of its own. The first generation technology system (1G) was represented by the analogue mobile systems, of which the most relevant for NorCom was NMT[1]. In 1981, the Nordic mobile telephony operators launched the first cross-national public mobile telephony system called NMT. The system was a huge success and attracted international attention with its high user penetration. In the late 1980s, a new generation (2G) began to emerge as European telecommunication operators decided to create a pan-European system based on digital technology. Both 1G and 2G systems dealt with voice calls and text messaging, but the use of digital network in the case of 2G enhanced the clarity in conversation and allowed for a semi-global roaming. Thus the cluster firms faced both increased technological complexity and increased international competition.

[1] Within each generation, different systems were developed in different parts of the world (e.g. Nordic countries, central Europe, the U.S., and Asia) and have been competing with each other. In this paper, only the technologies relevant for NorCOM cluster are discussed.

To overcome this disruption Dancall and Cetelco formed a joint venture company, DC Development, to develop the basic modules of a GSM phone together with the Department of Electronic system at Aalborg University. DC Development succeeded in developing the modules and the parent companies were among the first to produce a GSM phone. They were also active in the standardization process. Other firms in the cluster followed other strategies, like Maxon that decided to continue to make 1G phones and then move into 2G later on when the technology had slightly matured.

In the 1990s, more spinoffs were founded within telecommunication, producing mobile phones, chips, and components, or other supporting technologies. This development, however, was not smooth since several companies in the cluster went into severe financial and technological problems following the shift from 1G to 2 G. As the cluster was resilient in this period, some of the troubled companies and laid-off employees were taken over by other companies in the cluster and new companies entered the cluster. For example, the two companies that pioneered the development of the first GSM phones in the region – Dancall and Cetelco – were acquired by other firms in the early 1990s due to financial constraints. Cetelco was acquired by Hagenuk, who wanted to enter the promising mobile phone market, in 1990 and continued to grow afterwards. However, due to the unexpected high development costs, the company downsized the production after it had introduced the second version of GSM phone and eventually stopped production to focus on R&D. In 1998, the company was acquired by Telital. Dancall was also in financial troubles as the newly developed GSM phone was not competitive due to high price and the export of NMT phones suffered from the growing GSM phone market and the closing of the markets in the Middle East during the Iraq war. Consequently, Dancall was acquired by Amstrad in 1993. Then, the company gained momentum again and grew. Despite the financial difficulties, the total employment in the cluster increased constantly from 1992 and onwards.

By the end of 1990s, the number of firms in the wireless cluster has more than doubled. The high increase in the number of firms was mainly due to entry by spinoffs. Among 20 entrants in the 1990s, seven of them were entrepreneurial spinoffs, whose founders had experience in the cluster before the start-up and six of them were parent spinoffs, which were newly established subsidiaries of foreign companies. For example, Analog Devices, Lucent, Infineon, and Nokia entered the cluster by establishing a new branch. In this period, the ownership structure of the cluster has changed significantly as many multinational corporations (MNCs) entered the cluster either by creating a new organization as mentioned above or by acquiring local firms. The latter happened as the local firms experienced financial trouble due to declining markets or general lack of R&D funds for new technologies while large multinational players in the industry were looking for the new locations in order to access competences of local development engineers (Lorenzen and Mahnke, 2002). Maxon, Bosch Telecom, Telital and Texas Instruments are examples of MNCs that entered the cluster by acquiring already existing firms. In the late 1990s GSM had become a de facto global standard and sales boomed. In this high-growth period the firms hired engineers in bundles, mainly from the local university, but also from the firms outside the cluster. This, on the one hand, made the cluster more competitive by attracting talent, but on the other hand increased wages greatly, thereby reducing wage competitiveness of the cluster.

The second disruption (2000-2003) and the result

The cluster experienced an external shock in the early 2000s when the telecommunication sector was hit by stagnating sales after the burst of dot-com bubble. The MNCs in the cluster changed their strategies and either collected R&D units in the home country or reduced R&D expenses in the subsidiaries. Consequently, many of

the MNCs downsized and sacked local engineers. Some existing and new firms were able to absorb the released work force from the MNCs and some engineers even created their own companies. When Cetelco (then owned by Telital) closed down in 2002, some employees joined newly-established parent spinoffs by two other foreign companies, Advanced Wireless Design and Acolyte in 2003. Nokia decided to move its R&D unit to Copenhagen in 2001 and some employees from this unit established Wirtek. Some local firms were also affected by this crisis as Force Electronics, Partner Electric and Shima Communication closed in 2002. Force Electronics was divided into two entities after dissolution. Employees in the R&D department acquired their unit together with Novi A/S and Erhvervsinvest Nord and created a firm called Futarque. The production unit was acquired by Satellit Compagniet from Norway. Despite the downsizing and exit of MNCs and local firms, the number of companies grew in the same period as there were many new companies entering the cluster. The number of employees decreased slightly from 2000 to 2002, but it recovered and even reached the highest record in the history in 2003.

In a report from 2002 on the future of the wider ICT sector in the region, some of the managers for MNCs complained about the lack of local decision power in deciding R&D strategies. Others feared that the lack of closeness to end-users and lack of knowledge related to production might become a problem. Many of the companies acquired by the MNCs were dependent on single customers or on sale to other parts of the MNC. The shift from 2G to 3G also posed a threat to the cluster. The standardization process has become global planning to create a global standard. This implied that there would be global competition. The complexity of technologies had also increased by a factor 100 and the pressure on time to market had increased. The firms in the cluster had various strategies. Some firms were initially active in 3G research e.g. L.M. Ericsson (closed in 2003), others decided to wait and some firms tried to cooperate with others in developing the new technologies, but failed (Dalum et al., 2005). As a result the cluster was not very active in the new technology, which reduced its resilience. The composition of the cluster had changed during the late 1990s and early 2000s. The mobile communications industry had become much more complex and there was increasing convergence with the computer industry. Making mobile phones had become more modularized and specialized with companies specializing in batteries, screens, antennas, chipsets, software applications, print boards, assembly, test equipment etc.

The impact of disruptions in the early 2000s, dot-com bubble and transition from 2G to 3G, started to show in 2004 as many firms closed down or downsized while there was no entry between 2004 and 2006. The number of employees and firms began to decrease after the peak in 2003. This implies that the resilience has been damaged and the cluster could not reorganize itself after the shock. One of the big companies in the cluster, Flextronics, closed down with 500 employees in Pandrup in 2004. The company has lost a big order from the major customer Siemens and the headquarters in Singapore decided to move the production to low cost locations. Flextronics had its root in Dancall which has gone through restructuring several times with new owners since 1980s. Dancall Telecom was acquired by Bosch Telecom in 1997 which lasted 3 years before it was split into two companies, Flextronics and Siemens. As Dancall was the cluster's second oldest company which created many spinoffs, close-down of Flextronics was considered as a tragic event for the cluster. But the main layoffs were low-skilled production workers, while the engineering R&D competences continued in Siemens.

The third disruption (2007-2009)

The introduction of the iPhone in 2007 led to change in demand from traditional mobile phones to smart phones and 3G telephones have gradually taken over the mobile telephone market. While the companies in the cluster had to adjust to this big change, the financial crisis hit many economies around the world, resulting in decrease in general demand in all markets including mobile telephone markets. Consequently, these disruptions posed threat to some companies and some firms ended up exiting the cluster. For example, two central players in the cluster, Motorola and Texas Instruments (TI), ceased their activities in 2009. Motorola entered the cluster by acquiring BenQ which had taken over Siemens' activities in 2005 but closed down all the operation in Europe the very next year. However, the rapid growth of smart phones following the iPhone introduction in 2007 marked a new disruption to the cluster. Motorola's Aalborg division had focused on development of new mobile telephones and planning of production until the headquarters decided to pull out of European mobile market and reduce the number of newly developed models. TI acquired local ATL Research which was established as a spinoff from Cetelco in 1997. TI suffered from focusing on chipsets to 2G phones instead of 3G phones. Motorola and TI had to lay off respectively 275 and 75 employees in 2009 which worried the local actors in the industry. Unlike the former incidents where MNCs laid off many engineers at once, the industry could not take in all the engineers as it was not in the growing phase any longer. This resulted in work force migration to other regions in Denmark and to other industries. The cluster has not recovered its resilience since the second disruption in the early 2000s and still appears to have low resilience.

4.3. Role of university

The presence of Aalborg University has been very influential for the development of the cluster. Since the university was established in Aalborg, the capital of the region of North Jutland, in 1974, its biggest role has been to supply highly-skilled knowledge workers – engineering graduates – to the industry. In the beginning, there was a good match between the few existing radiocommunication firms and the profile of researchers in electronic engineering. The high quality human resources within the field proved to have attracted MNCs just for the purpose of recruiting the engineers from Aalborg University. Although the indirect transfer of knowledge via graduates has been the most substantial role of Aalborg University, direct research spillover also took place to a certain degree. Center for Personal Communication (CPK) established at Aalborg University in 1993 played an important role in this type of knowledge spillover as this center was strategically set up to focus on basic research in radiocommunication technology and speech recognition. This was followed by the establishment of the large research unit Centre for TeleInFrastructure (CTIF) in 2004, focusing on 4G technologies.

When the technology shift from 2G to 3G was about to happen, there was increasing concern within the cluster that the local firms have not been actively developing the fundamental technologies for this new emerging system. Although basic 3G research has been conducted at the university, it has not encouraged the firms to actively engage in the development of commercial products based on these technologies. Therefore, one could argue that the university as a source of new knowledge failed to address the problems that dampened the resilience in a timely manner. However, the university and industry co-evolve. When the industry boomed the graduates went into this sector and resources were given to R&D. Today the university still collaborates with the industry leaders, but these are located in Asia.

4.4. What changed resilience of the cluster over the years?

Table 1 shows the three disruptions that the cluster faced over time, the dynamics within the industry and cluster at the time of disruptions, and the impact of the disruptions and the level of resilience observed after the disruptions. The cluster was resilient after the first disruption in the late 1980s and continued to grow afterwards. However, the resilience appears to have weakened between the first disruption and the second disruption as the cluster was unable to recover from the shock in the early 2000s and started to decline. When the most recent threat hit the cluster, the situation has not changed. The cluster continued to lose important companies. In this section, some factors that have weakened the resilience over time are discussed with the focus on the changes between the first and the second disruption periods.

First of all, the most important factor that changed between the two disruptions was presence of relevant technological competence at the time of transition from one generation of system to another. In transition from 1G to 2G, two firms in the cluster formed joint venture in order to develop the basic technologies ahead of other competitors elsewhere. The joint venture company, DC Development, succeeded in developing GSM technologies and the two parent companies, Dancall and Cetelco, were among the first to produce the GSM phones in the market. Sonofon which was the first private GSM operator decided to build its main operations in Aalborg and there were several other companies in the cluster that continued to develop GSM equipments. The technological competence broadened as some companies founded a joint venture Dansk DECT Udvikling to focus on ETSI standard for cordless phones while others went into the field of Bluetooth standard. Chipset companies like Texas Instruments and Infineon entered the cluster. This broadening of the market and knowledge base increased the resilience. However, when 3G emerged, the development of basic 3G technologies did not take place in the cluster to the same degree as the development of the 1G and 2G took place in the past (Dalum et al., 2005). Collaboration effort initiated by some firms did not succeed and one major company invested in 3G technologies left the cluster. 3G proved to be a major technological disruption and attracted some new players to the industry. The technology is vastly more complex than 2G and requires huge investments in R&D that only large companies can afford. Consequently, the technological competences within 3G were mainly developed in other parts of the world, where the development costs are lower (e.g. Asia). Therefore, the lack of these competences in the cluster seemed to have hindered new firm formation between 2004 and 2006, which contrasts heavily from active entrepreneurial activities in the late 1990s and even the very early 2000s. Few years later, when the third disruption reached the cluster, this has also influenced some central companies' (e.g. Motorola and Texas Instruments) decision to cease the activities in the cluster.

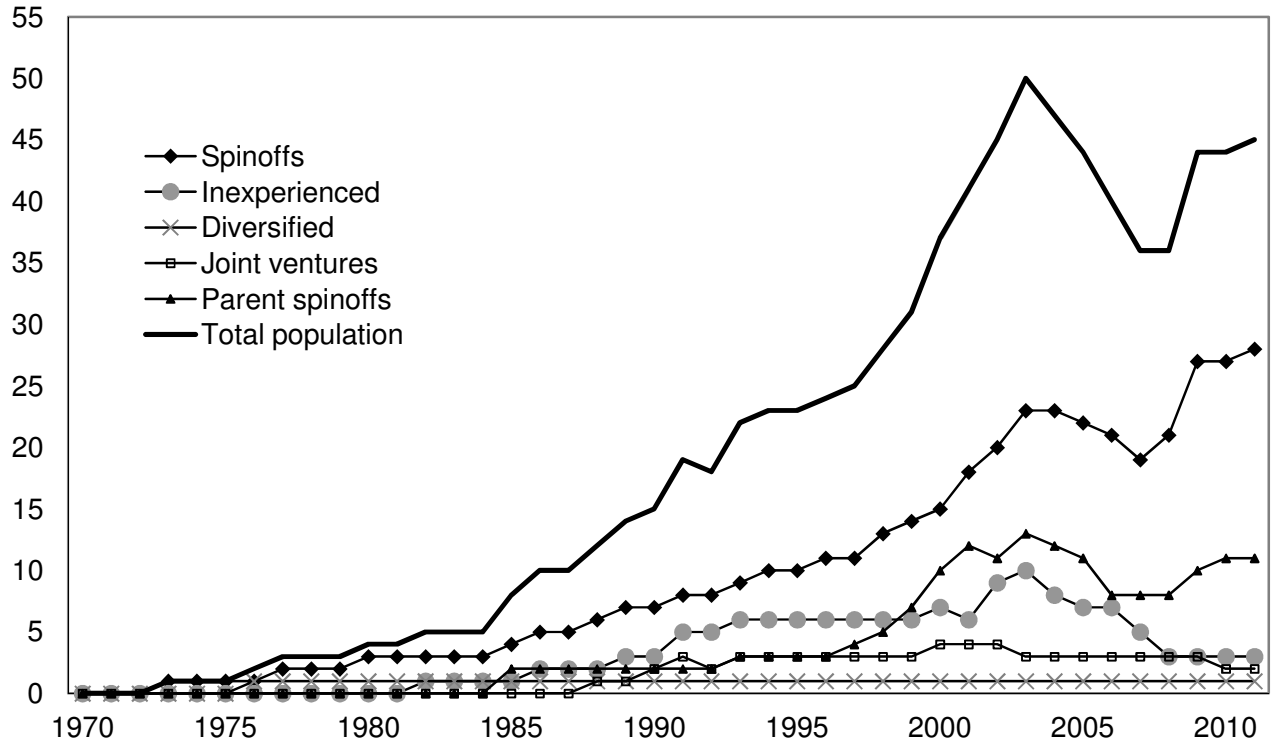
Another factor that might have affected the decline after the second disruption is exit of firms that had created many spinoffs in it lifetime. Entrepreneurship has played a critical role in the evolution of NorCOM. Dahl et al. (2010) concluded that entrepreneurial spinoffs from the existing companies have been the main driver of the formation and development of the cluster until the early 2000s. Looking at the change in the population of firms by entry types (see figure 4), it is hard to deny that spinoffs, especially entrepreneurial spinoffs, largely account for the development of the cluster over the whole time period. The spinoff process was especially important in the very early emergent phase where S.P. Radio created offspring that diversified into mobile telecommunication.

Table 1 Major disruptions in the cluster and resilience after each disruption

	1988-1992	2000-2003	2007-2009
External disruptions/ Threats	New standard: 1G (NMT) to 2G (GSM) - From analog to digital - From Nordic to European - Increase in complexity	New standard: 2G (GSM) to 3G (WCDMA/UTMS) - From European to world wide - Increasing complexity Tele service providers and 3G spectrum auctions Dotcom crisis around 2001	New standard: 3G (WCDMA/UTMS) to 4G (LTE) - Importance of data transmission Introduction of smartphones - Convergence from communication to computing Financial crisis: decrease in general demand
Industry dynamics - Demand - Competition - Structure - Technology	Larger market spanning the whole Europe Increasing demand for mobile phones Increasing competition Entry by large electronic firms Large scale production Intense technology development Shorter product life cycle	Larger market spanning the whole world Increasing demand Mega competition Alliance between incumbents (e.g.Sony Ericsson) Entry of MNCs from other standards Large scale production Intense technology development Shorter product life cycle Increasing specialization/ modularization	New entry : Apple, Google, and Microsoft New control systems Increasing importance of software products like apps New path in technology development Decline of old incumbents such as Nokia, Motorola, and Sony Emergence of new leaders: e.g. Apple, Samsung, HTC Emergence of new markets: e.g. China, India
Cluster dynamics - Structure - Strategies - Policy	Around 15 firms in the cluster Joint venture (DC Development) by Dancall and Cetelco to develop basic 2G technologies. Some other firms continued with 1G phones (e.g. Maxon) Science park NOVI providing entrepreneurial environment to firms Collaboration with Aalborg University and National Telecom Agency	Around 45 firms and 4000 employees in the cluster Number of MNCs in the cluster has increased Specialization by developing different components of mobile phones CTIF established at Aalborg University to focus on 4G technologies Some firms that used to be seedbed for entrepreneurial spinoffs exited Fragmented strategies of firms led to lack of 3G competences in the cluster - Attempt on collaboration on 3G failed - Maxon did not move into 3G - Ericsson with 3G competence closed down - Siemens started offshore outsourcing	Around 40 firms and 2200 employees in the cluster Increasing number of software firms MNCs in crisis Exit of some major firms Diversification among firms Industry organization merger between NorCOM and ICT Forum CTIF still focusing on 4G technologies Entry by spinoffs from exiting firms
Result - Resilience - Evolution	Number of firms increased continuously Troubled firms acquired by MNCs - Dancall was acquired by Amstrad - Cetelco was acquired by Hagenuk Laid off employees were hired by other firms in the cluster. Resilience was high and the cluster was still in the growing phase	Number of firms and employees started to decrease in 2004 No entry between 2004 and 2006 Resilience was lower than before and the cluster showed signs of decline	Decrease in the number of employees seems to be stabilized while the number of firms increased with new spinoffs from exiting firms Resilience in question - Firms that generated many spinoffs closed down - Survival of new firms is also in doubt Continued decline or possible transition

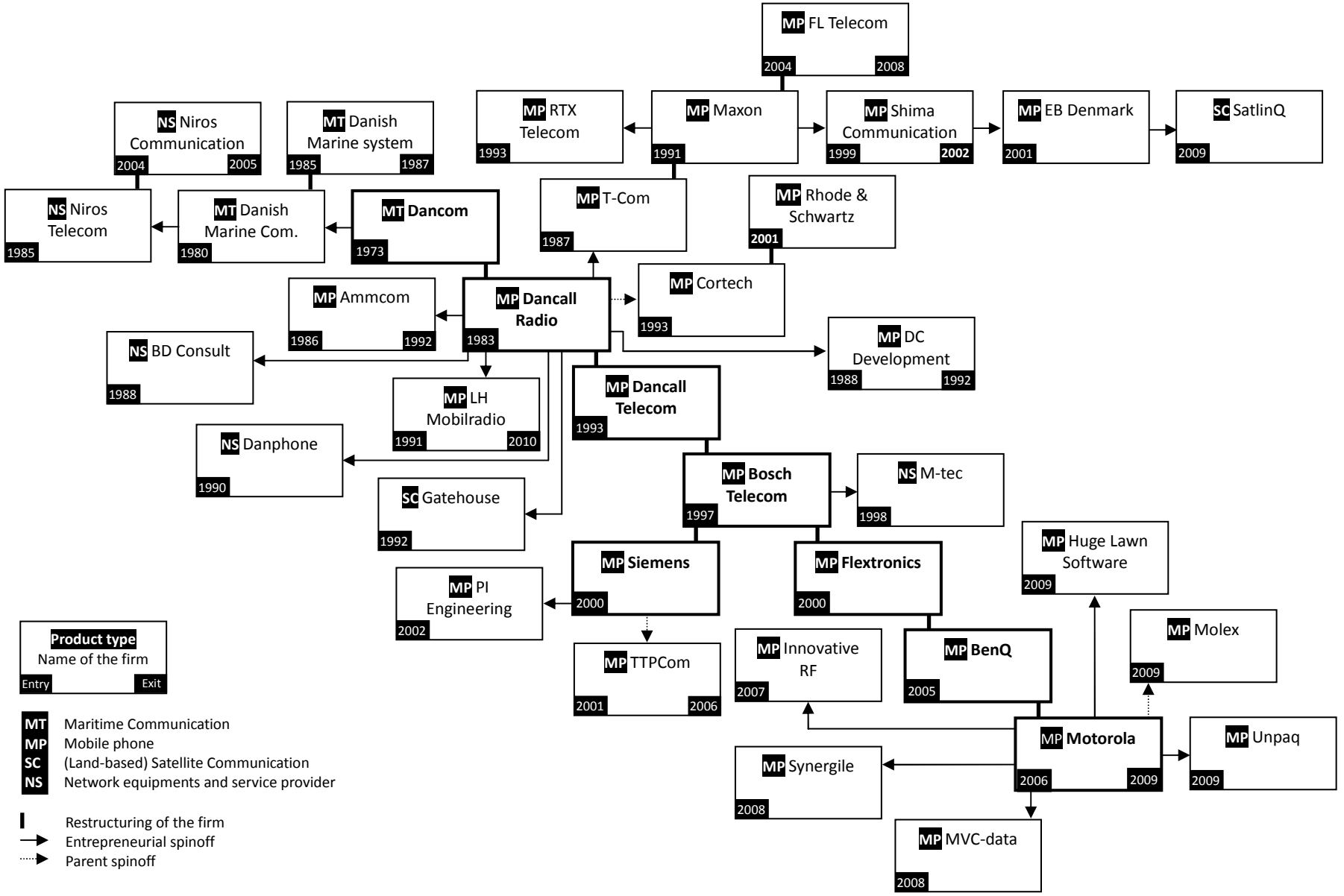
The existence and survival of Dancom and Cetelco, the two seedbeds for many spinoffs later on, was also crucial for further development of the cluster (see figure 5). However, one of the forefathers of the cluster –Cetelco– exited in 2002. This company had five spinoffs during its life. One of its spinoffs, ATL Research (later acquired by Texas Instruments and exited in 2009), also became seedbed for new firms as total six spinoffs came from this company. In 2003, L.M. Ericsson, which was parent to four firms in the cluster have ceased its activities. This spinoff history over few generations confirms that some firms function as training ground for entrepreneurs who gain relevant capabilities and routines from the parent companies. Therefore, it is unfortunate that these firms exited the cluster, possibly affecting the level and quality of entrepreneurship in the cluster in the future. This might explain the low level of entry in the past six years with the exception of year 2009.

Figure 4 Firm population by entry type



The next factor that changed between the two disruptions was the concentration of MNCs in the cluster. After the first disruption, some local companies were acquired by foreign firms due to financial problems. Moreover, more MNCs entered the cluster in the following years in the 1990s as they were attracted to the competence level in the cluster. However, high concentration of MNCs showed weakness during the time of crisis. Many MNCs present in the cluster had headquarters in other countries and the units in North Jutland did not have much influence on strategic decisions made by the headquarters. Especially when the mobile telecommunication sector had crisis in the early 2000s and the financial crisis hit the economies worldwide in 2008, many of these MNCs had to reorganize their activities to stay competitive in the market. Motorola and Texas Instruments decided to focus on other technology areas and Ericsson gathered its development activities to bigger R&D centers.

Figure 5 Dancom and its spinoffs



Source: Own illustration

Lastly, high wage level in the cluster also became a serious disadvantage when the competitors in other parts of the world began to develop new technological competences, leading the transition to newer generations. Consequently, this has caused some firms to close down in North Jutland. The wage level of highly qualified engineers had skyrocketed during the 2000s because of the increase in demand for specialized labor. High production cost in Denmark was also a disadvantage for some firms that were involved in the production of mobile phones and components. When Flextronics and Navico closed down the production in North Jutland, the companies indicated that the production will be relocated in low-cost locations.

All in all, lack of technological competences for the new dominant mobile system combined with dissolution of entrepreneurial sources and strategic decision made by MNCs have weakened the cluster's resilience to the second shock that the cluster faced. These are the conditions that differ from the late 1980s when the cluster experienced the first disruption. In other words, technological and cognitive lock-in could be identified as major causes since the cluster was not active in developing new technological competences within 3G. Focusing on the competences the firms already had they probably were not able to recognize the trend in the market and acknowledge the need to develop new ones. As a consequence, not only this led to many firm exits in the cluster, but it also limited the opportunities for new businesses, resulting in a very low entry level. The underlying technological trend with convergence with computer industry and market conditions marked by mega competition also fuelled the decline[2].

5. Discussion

In this section, the findings from the case study are discussed in relation to the prior work on cluster decline and resilience.

As it is often pointed out as a cause of cluster decline, 'lock-in' proved to be one of the main factors that led the cluster to decline in the case of the wireless communication cluster in North Jutland. In this case, cognitive lock-in among cluster firms perhaps brought about technological lock-in as they focused on further development of the already existing technological competences in 2G instead of being active in developing new technologies that later formed the global standard system in mobile communications. This is also in line with the argument by Martin and Sunley (2006) that processes and configurations built op in the phase of 'positive' lock-in – in this case, the phase when GSM technologies flourished and created positive externalities – become a source of increasing inflexibility and rigidity. However, the downturn of this cluster is a result of multiple factors, including both internal and external factors. The most important external factor could be changes in the market and the industry. Falling demand for the cluster's GSM-based-products since the emergence of 3G telephones clearly affected the recent firm closure in several cases. As Porter (1998) argued, technology discontinuity (transition from one generation of system to another) and changes in demand in the industry has indeed been the disruptions that interfered with the growth of this cluster.

[2] Recently, the large western mobile communications companies have performed badly. L.M. Ericsson entered a joint-venture with Sony, which recently acquired the entire company. Nokia is closing many of its Nordic R&D centers including the center in Copenhagen with 1,200 engineers. Motorola exited the industry and sold its Motorola Mobility to Google.

What accelerated the downturn was the strong presence of MNCs in the cluster. When the cluster was in a growing phase with the strong competence in GSM system, many MNCs entered the cluster to get access to high skilled labor in the cluster. This confirms that MNCs to an increasing degree enter new locations with the purpose of 'technology-sourcing' (Fosfuri and Motta, 1999). However, they have been reactive to changes in the industry as they readily downsized the organization or exited the cluster during the crises, proving that they are much more 'footloose' than local firms (Görg and Strobl, 2003). This 'footloose' characteristic needs to be understood in relation to the functions that the subsidiaries had in the cluster. The majority of these organizations were R&D units and that might have increased reactive-ness of these firms as relocation of R&D units is less costly than that of production sites. As a result, the presence of MNCs, which used to be considered positive as they entered the cluster by saving some local firms from bankruptcy, clearly affected the resilience of the cluster in the occasion of external shocks.

Finally, new firm formation is found to be of great importance for cluster resilience when the cluster is facing disruptions. When external shocks hit the cluster, firms close down. For a cluster, a way to reorganize itself and recover from this situation is by means of entrepreneurship. This is also proven in our case when the cluster had crises in the late 1980s. During this crisis when firms started to exit, new organizations entered the cluster by either acquiring troubled firms or establishing new entities with laid-off employees. Simmie and Martin (2010) argue that Cambridge high-tech cluster recovered from early 1990s recession by continuously branching out sub-clusters based on the strong knowledge platform in advanced mathematics and computing. In the case of Cambridge, the number of new firms in the cluster also continues to grow in the 1990s driving the economic growth after the recession. However, when new firm formation slows down or stops, as in the case of the cluster in North Jutland between 2004 and 2006, the cluster cannot recover from the continuous firm exit and therefore become vulnerable, especially in difficult times. Decrease in new firm formation is also observed in the Cambridge cluster in its declining phase around 2005-6 (Stam and Garnsey, 2009). Similar to the wireless cluster in North Jutland, the decrease in new firm formation was more dramatic than the increase in number of exits, fueling the decline of total population of firms in the cluster. As establishment of new firms creates variation within the cluster, it is important for evolution of clusters.

In their study on the decline of Cambridge high tech cluster, Stam and Garnsey (2009) pointed out few other meaningful factors for cluster evolution, which are also relevant for the cluster in this article. First of all, the role of university as continuous supplier of new knowledge is highlighted in both cases. For high-tech clusters utilizing emerging technologies, access to continually renewed pool of talent and knowledge is crucial. Universities might help troubled clusters renew themselves by introducing new knowledge, just as the Cambridge case showed in 1990s. In the same way, Aalborg University's recent effort in developing 4G technologies might lead the wireless cluster out of the current crisis. Another factor urged by the authors for further investigation in relation to cluster decline is the impact of acquisition of local firms. When firms are acquired and relocated elsewhere, the cluster loses basis for local innovation and job creation. In the case of the cluster presented in this paper, acquired firms often were dissolved by the decision of the headquarters in the times of crisis rather than being relocated, but it still had the same effect on innovation and job creation.

6. Conclusions

The wireless communication cluster in North Jutland is a rather mature cluster that has existed for 40 years in a rapid changing industry. By following its evolution path utilizing the concept of resilience, we conclude that the cluster seems to be in a declining phase since 2004 because of the weakened resilience which is interpreted in this paper as an adaptive capability of a cluster to external shocks. In our case, cluster's resilience is examined in terms of new firm creation and employment retention in the cluster following firm closures in the time of crises. The cluster faced three major disruptions in its history, mainly associated with transition from one mobile communication standard to another. The first disruption came in 1988-92 when the transition from 1G (NMT) to 2G (GSM) took place. The second disruption was marked by transition to 3G and the dot-com crisis in the early 2000s. The most recent disruption in 2007-9 was related to the global financial crisis and the advent of smart phone.

After the first crisis, this cluster was able to recover from shock as it reorganized itself and continued to grow. However, after the cluster experienced the second disruption, new firm creation stopped and the number of employees continued to decrease from 2004. In 2009, the situation has gotten worse as a substantial part of the former employees of Motorola and Texas Instruments left the cluster when the two firms exited. As is often assumed, there were multiple causes for the cluster decline. Several factors have been pointed out to have influenced the resilience of the cluster in recent years. Technological lock-in, exit of firms that have been major sources of spinoffs, and lack of control on MNCs decisions elsewhere have all contributed to impairment of the cluster's adaptive capability to a major shock in the industry – technology shift from one generation to another. What can be learned from this case is as follows. When the technological competences in a cluster cannot catch up with the technology development in the industry, the cluster will be less resilient to shocks/changes. When the cluster's competences become 'old', new ones should be emerging in a timely manner. However, technological lock-in often comes with cognitive lock-in that it would be hard for the cluster firms to engage in developing new technologies. Then, the role of industry organizations as a supporting organization and local universities as a source of new knowledge becomes important. For clusters to be resilient, it is also important to have 'local' firms that are rooted in the region. Clusters with high concentration of MNCs proved to be vulnerable to shocks as multinational firms are footloose. MNCs might not be as embedded as 'local' firms in the region, which might also hinder collective efforts to overcome crises.

Our study contributes to the cluster literature in the following ways. First of all, the case study reveals the process of decline of a high-tech cluster. In contrast to ample empirical research on emergence and development of clusters, relatively little is known about how clusters evolve over time and decline. The accumulated data on all firms that have existed in the cluster including entry and exit year, founder's background, the major events, and the number of employees allows us to follow the entire development path from emergence to decline and identify the factors that specifically influenced the downturn. Moreover, while most studies on declining clusters deal with industries that are in decline itself, this paper studies a cluster in a high-tech industry, which is relatively new and still growing, therefore being able to highlight the capability of a cluster in the analysis of decline. Second of all, we utilize the concept of resilience, which proved to be quite useful in analyzing an adaptive capability of a cluster in the time of crises. Resilience can benefit the research on evolution of clusters as this should be understood as a result of the interaction between different internal and external factors. Lastly,

we emphasize the role of MNCs in regional clusters in an attempt to enhance the understanding of interaction between a cluster and MNCs.

Our findings point to some relevant future research areas. Firstly, it would be interesting to study how wireless communication clusters in other regions (and countries) have evolved in the same period of time to find more location-specific factors that affected the evolution of the clusters. Secondly, how resilience of regional economy is related to that of cluster is an area of study that needs more attention as this has policy implications for both regional economies and clusters.

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