What Makes Clusters Decline?

A Study on Disruption and Evolution of a High-Tech Cluster in Denmark

Østergaard, Christian Richter; Park, Eun Kyung

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Christian Richter Østergaard
(cro@business.aau.dk) Corresponding author
Department of Business and Management, Aalborg University, Fibigerstraede 11, 9220, Aalborg Oe, Denmark

Eunkyung Park
(eunkyung@business.aau.dk)
Department of Business and Management, Aalborg University, Fibigerstraede 11, 9220, Aalborg Oe, Denmark

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Abstract

Most studies on regional clusters focus on identifying factors and processes that make clusters grow. However, sometimes technologies and market conditions suddenly shift, and clusters decline. This paper analyses the process of decline of the wireless communication cluster in Denmark. The longitudinal study on the high-tech cluster reveals that technological lock-in and exit of key firms have contributed to decline. Entrepreneurship has a positive effect on the cluster's adaptive capabilities, while multinational companies have contradicting effects by bringing in new resources to the cluster but being quick to withdraw in times of crisis.

Keywords: Regional clusters, cluster decline, adaptive capabilities, wireless communication industry, high-tech, disruption

JEL codes: R11, R12, O33, L26

1. Introduction

Regional clusters have gained much attention from scholars and practitioners over the last 20 years. One of the aspects investigated intensively in cluster research is the emergence and growth of clusters. In contrast, relatively little is known about how clusters evolve over time and why some clusters decline. The survival of clusters is of great interest for policy makers, as decline will cause turmoil in regional economies. Detailed empirical studies on cluster decline are thus crucial in order to reveal patterns in how clusters decline.

It is commonly observed that disruptions, which often come from sudden changes in the industry, key technologies, and the market, pose threat to clusters. The seminal work by GRABHER (1993) on the decline of the Ruhr district describes how the cluster started to decline after a disruption in demand. He argues that firms were not able to adapt to the disruption because of lock-in. Examples of Silicon Valley and Route 128 also show how disruptions affect clusters. Both clusters experienced disruption in the 1980s: Silicon Valley faced fierce competition from Japanese chipmakers and had to give up the RAM module market, while Route 128 lost its customers as they shifted from minicomputers to workstations and personal computers (LANGLOIS and STEINMUELLER, 1999; BEST, 2001). Both clusters survived the threats, but in other cases, clusters start to decline after disruptions. The lack of capabilities to make changes to overcome internal and external disruptions – adaptive capabilities – (MARTIN and SUNLEY, 2006; HERVÁS-OLIVER and ALBORS-GARRIGÓS, 2007) appears to be a key issue in explaining cluster decline.

Clusters are often defined as "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). The adaptive capabilities and the evolution of clusters need to be studied in consideration of the interaction among these various economic actors, taking into account the developments in industry, technology, and institution and the heterogeneity in actions of firms. As Evolutionary Economic Geography (EEG) is concerned with the processes by which the spatial organisation of economic activities is transformed over time with attention to micro-behaviours of economic agents (BOSCHMA and MARTIN, 2007), it provides an important research framework for studies of evolution of clusters (MENZEL and FORNAHL, 2010; MARTIN and SUNLEY, 2011) and evolutionary processes of regional economic development (MARTIN and SUNLEY, 2006; BOSCHMA and FRENKEN, 2006; BOSCHMA and MARTIN, 2007).

This paper investigates the process of cluster decline. The conclusions derived in the paper are based on a detailed case study of the wireless communication cluster in North Jutland, Denmark. The high-tech cluster emerged in the 1980s and grew quickly during the 1990s; however, it showed signs of decline around 2004. In its history, the cluster experienced three disruption periods. The cluster survived the first technological disruption in the late 1980s. When the second disruption period, with a technological disruption and an economic recession, hit the cluster in the early 2000s, entry of new firms stopped, while exits increased. This process of decline was enhanced in 2009, when the third technological disruption and another economic recession came, and the two largest R&D firms closed down within a few months.

The paper contributes to the literature in the following ways. Firstly, the paper provides a detailed longitudinal study on cluster decline, which is rather scarce in the literature. The data that span the whole history of the cluster allowed the analysis of the decline in light of the development path that the cluster has experienced. Secondly, the explanation for cluster decline with attention to disruptions and lock-in contributes to the discussion in EEG. The paper argues that clusters are often exposed to disruptions and they start to decline when the cluster's adaptive capabilities are limited in the time of disruptions. Firm-level dynamics including the relations among the firms and the joint action in the cluster can shed light on how adaptive capabilities change. Lastly, unlike other decline studies focusing on the industries that are in decline itself, this paper studies a cluster in a growing high-tech industry.

The analysis reveals that technological and cognitive 'lock-in' and the exit of focal firms in the cluster was the major force that hampered the adaptive capabilities of the cluster. Innovation and new firm formation are identified as the factors that increase the cluster's ability to overcome threats, while the presence of foreign multinational corporations (MNCs) is found to have two contradicting effects. On the one hand, foreign MNCs increase the employment level and bring investments and new knowledge into the cluster, but on the other hand, they are ultimately footloose and will quickly withdraw from the cluster in times of crisis.

Theories of cluster decline are presented in Section 2. Section 3 describes the methodology. The case is described in section 4. The conclusions and discussion follow in section 5.

2. Theories of cluster decline

2.1. Cluster decline and life cycle

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 labour 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. Labour 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 the 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.*, 2013). SORENSEN and AUDIA (2000) find both a higher start-up rate and a higher exit rate in clusters, which indicates the existence of negative externalities. These negative externalities might hamper the development of the cluster and even be the cause of decline.

In the literature, there has been a tendency to link cluster evolution with industry life cycle. KLEPPER (2010)'s theory on the origin and growth of industrial clusters implies that the growth in the industry gives opportunity for clusters to grow through spinoff activities. TER WAL and BOSCHMA (2011) explain how clusters co-evolve with the industry and its technological properties at the macro-level, with the firms at the micro-level, and with the knowledge network of firms in the industry. As the industry matures, it experiences shakeout, during which less-competent firms end up exiting the cluster (KLEPPER and SIMONS, 2005; KLEPPER, 2010). At the same time, the variety of firm capabilities decreases and the network of firms become more stable, which might lead to cognitive lock-in and interfere with future learning. On the other hand, some studies suggest that cluster life cycles are different from industry life cycles. MENZEL and FORNAHL (2010) argue that different growth paths of the computer industry in Boston and Silicon Valley indicate that the cluster life cycle is not the local representation of the industry. Instead, they suggest a four-staged cluster life cycle going from emergence, growth, sustainment and decline and argue that the diversity and the heterogeneity of knowledge within the cluster provide foundation for the cluster's development. According to them, clusters decline when the heterogeneity cannot be sustained.

The critics of the life cycle approach claim that the concept implies a deterministic and smooth evolution that does not fit with empirics (MARTIN and SUNLEY, 2011). The emergence or growth of a potential cluster might be stopped and turn into decline at any point of the life cycle. MARTIN and SUNLEY (2011) therefore suggest a modified 'adaptive cycle model' in conceptualizing cluster evolution. This model recognizes that there exist two-way interactions between a cluster and its external environment and

posits that there are numerous development trajectories for cluster evolution, based on the four basic phases of the adaptive cycle model: exploitation, reorganization, conservation, and release. Among the trajectories, non-generative decline and cluster disappearance, which correspond to the decline in the standard life cycle terminology, is found to be the outcome of high internal connectivity and rigidity. High internal connectivity and rigidity may indicate poor adaptive capability, which is considered one of the important characteristics of a cluster that changes over the phases in the adaptive cycle model.

Therefore, to understand cluster decline, it is necessary to look at the cluster's adaptive capabilities in relation to shocks, such as economic recessions, environmental disasters, market disruptions and technological disruptions. Technological disruptions in particular change the underlying knowledge base for an industry and can easily lead to decline if the cluster firms are not able to move into the new technology (STORPER and WALKER, 1989; CHRISTENSEN, 1997; DALUM *et al.*, 2005; KLEPPER, 2010). The disruptions could also be linked to changes in the industry life cycle during an industry shakeout. During the shakeout phase, exogenous innovations (JOVANOVIC and MACDONALD, 1994) or endogenous innovations (KLEPPER and SIMONS, 2005) create less space for new firms and increase the exit of technology laggard firms, which change the industry structure and leave room for fewer clusters.

2.2. Cluster decline, identity, and adaptation

Cluster decline does not necessarily lead to disappearance of all activities within a thematic field, but is linked to a loss of identity. The identity can be understood as the regional industrial identity, suggested by ROMANELLI and KHESSINA (2005), which emerges from the shared perception of internal and external audience about the features of the industrial activity in a certain region. Internally, clustered firms share the sense of community that are often tied to specific technology and product characteristics e.g. a software cluster, or a wireless communications cluster (STABER and SAUTTER, 2011). MENZEL and FORNAHL (2010) state that a declining cluster can transform itself by moving into a completely new field. Similarly, MARTIN and SUNLEY (2011) suggest that, when a cluster reorganises itself, it can either renew itself and start a new cycle of growth or it can be replaced with a new one, with new identity and new function. However, when the replacement or transformation happens, it cannot be considered the same cluster afterwards due to the change in the identity.

A clusters is a population-level concept. It is important to remember that a cluster consists of many firms and organizations that have different strategies. The only way the cluster can change is through the actions of individuals, firms and other organisations, all of which may react very differently to the same

change. However, the reaction of a cluster as a whole appears to be more than the combined effect of reaction of individual actors because of the interconnections among them. SCHMIZT (1995) argues that the joint action of clustered firms can be an important element in overcoming challenges. Therefore, it is necessary to investigate the actions of different actors and the joint action among them at the same time when studying cluster evolution. The adaptive capabilities of the cluster depend on various factors, such as the rate of new firm creation, the innovativeness of incumbents, and the willingness of the firms to move into new fields, (BEST, 2001; HERVÁS-OLIVER and ALBORS-GARRIGÓS, 2007; MENZEL and FORNAHL, 2010; MARTIN and SUNLEY, 2011; HOLM and ØSTERGAARD, 2015). On the other hand, the lack of these factors will affect the evolution of the cluster negatively. In the rest of the section, the key factors that influence cluster evolution will be discussed.

Lock-in

According to GRABHER (1993), lock-in consists of factors that diminish a cluster's ability to recognize and make adjustments to sudden changes. GRABHER identifies 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 worldview or mindset that makes it hard for them to respond to outside changes. Political lock-in concerns institutional effort to maintain existing industry structures which might damage the development of creativity.

The case of the Ruhr area shows that lock-in affects cluster evolution negatively (GRABHER, 1993). The Ruhr area faced disruptions stemming from falling demand and rising competition as early as in the 1960s. However, the functional lock-in led to lack of innovation among suppliers, which were suffering from 'dependent supplier syndrome', and the groupthink from the cognitive lock-in made the firms believe that the worrying demand trend was only a short-term disruption. The firms were thus not able to respond in a timely manner to the changes in the environment. Cognitive lock-in is a fundamental problem for cluster firms in reacting to external changes. POUDER and ST. JOHN (1996) assert that the managers in the clustered firms have similar mental models because they have similar industry experience and educational training within a certain field. Through the origination and convergence phase of cluster, the existence of similar mental models and the proximity among the clustered firms induce groupthink as managers direct attention mostly towards the other cluster firms rather than firms outside the cluster and create narrow focus on their strategies. The clustered firms will eventually act differently than non-clustered firms and can miss out signals from outside the cluster, which can be critical for the continuity of the cluster.

Cognitive and functional lock-in can also lead to technological lock-in, if the firms are too focused on the current products and technologies or if the firms have not developed sufficient innovative competences. Then, they are less attentive to developing new technologies and products, which will also lead to a low level of entrepreneurship within firms (intrapreneurship). All in all, lock-in in incumbents leads to lack of innovation and intrapreneurship, which in turn makes the cluster less adaptive when the technologies shift in the specific field..

Lack of new firm creation

When clusters experience lock-in and show tendency to decline, new firms can be a source of revitalization. The Ruhr case described by GRABHER (1993) proves that new firms contributed to the eventual reorganization of the industrial district that followed the decline. During the last half of the 1980s, some firms moved headquarters and R&D departments to other regions. Steel firms changed their strategic direction and began to focus more on 'processing of steel', diversifying into plant engineering, environmental technology, mechanical engineering, and electronics. A new industrial complex in environmental technology was formed, comprised mainly of newly established firms. Thus, entrepreneurship was one of the forces that drove the renewal of the old industrial district.

Similarly, SAXENIAN (1990) found that the high rate of new-firm formation in Silicon Valley fostered industrial adaptation in the 1980s, when semiconductor producers were challenged by Japanese competitors. Unlike the established companies in the region, these new firms began to specialise in certain areas of expertise, such as chip design and fabrication processes, and contributed to strengthening the competitiveness of the region as a whole. SIMMIE and MARTIN (2010) argue that the Cambridge high-tech cluster recovered from the early 1990s recession by continuously branching out in sub-clusters based on a strong knowledge platform in advanced mathematics and computing. New firms played an important role in this process. On the contrary, lack of new firms could lead a cluster to a declining phase. As it is illustrated in the cases above, new firms provide an opportunity for a cluster to move into related areas of expertise. When clusters experience shocks and need to adapt to the change, new firms can be the driver for the change.

Among the different types of entrants into clusters, spinoffs are found to be especially important for cluster evolution (BUENSTORF and KLEPPER, 2009; DAHL and SORENSON, 2009). Spinoffs, defined as firms established by entrepreneurs with experience from existing firms in the same industry, tend to locate close to the 'parent' companies and perform better than other entrants, thereby driving the formation of clusters. However, some firms are better training grounds for entrepreneurs and create more

spinoffs than others, while some companies never produce a single spinoff (KLEPPER, 2010). If the first type of company closes down, it limits the cluster's adaptability through entrepreneurship.

Role of foreign multinational corporations

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 knowledge activities by the MNCs will depend on their motives for entering in the cluster and their roles in the MNC knowledge networks.

CANTWELL and MUDAMBI (2005) distinguish the subsidiaries with competence-creating mandate from the ones with competence-exploiting mandate, using the analogies to exploration and exploitation in organisational learning theory. As the subsidiaries with competence-creating mandate invest in R&D activities that are qualitatively different from the 'locally adaptive' R&D activities of the subsidiaries with competence-exploiting mandates, this kind of subsidiary will be more active in innovation activities and therefore will have positive influence for cluster's adaptive capabilities. However, when competence-creating subsidiaries are located in a highly concentrated industry, they become more like an outsider in the inter-firm network in the host country and therefore are inhibited in terms of knowledge inflows from the local innovation systems (CANTWELL and MUDAMBI, 2011).

DE PROPRIS and DRIFFIELD (2006) found a positive spillover effect of FDI in clusters. This demonstrates that MNCs can have positive influence on the cluster's adaptive capabilities by enhancing other cluster firms' competitiveness. The knowledge acquired via the global pipelines can be beneficial not only for the firms directly connected to the pipeline, but also for the other firms in the cluster through spillover effect (BATHELT *et al.*, 2004). The connection outside the cluster also contributes to increasing the heterogeneity of knowledge, which makes the cluster sustainable over a longer period of time (MENZEL and FORNAHL, 2010).

The existence of foreign MNCs in the cluster can also have some negative sides. BIRKINSHAW and HOOD (2000) found that a high level of foreign ownership in cluster is negatively related to cluster dynamism, which may indicate that clusters with high foreign ownership are less sustainable in the long run. High foreign ownership was also negatively associated with subsidiary autonomy and capabilities in this analysis. Moreover, foreign-owned firms are less-committed than indigenous ones. Foreign firms are more likely to restructure, relocate, sell, and close down units in times of economic downturn (GÖRG and STROBL, 2003). The effect of foreign MNCs on the cluster's adaptive capabilities is thus a double-edged sword, as these companies bring knowledge and resources to the cluster, but might also leave quickly and

hamper the dynamics within the cluster. If the MNCs are not embedded in the local knowledge network and do not participate in the joint action when it is needed, they can affect the cluster evolution negatively.

3. Methodology

3.1. Data collection

The wireless communication cluster in North Jutland is a relatively small and young cluster in a high tech industry that emerged in the 1980s and began to decline in the mid-2000s. Despite its small size and relative short history, firms from the cluster were important players in the early growth phase of the mobile communications industry. In addition, several important innovations, such as the embedded mobile phone antenna, were developed in the cluster. This well-studied cluster makes it possible to follow the cluster's evolution closely and to study how the firms and institutions in the cluster reacted to three periods of disruption. The case resembles a critical case, and therefore it can be argued that what makes this high-tech cluster decline can also lead other clusters to decline (FLYVBJERG, 2006).

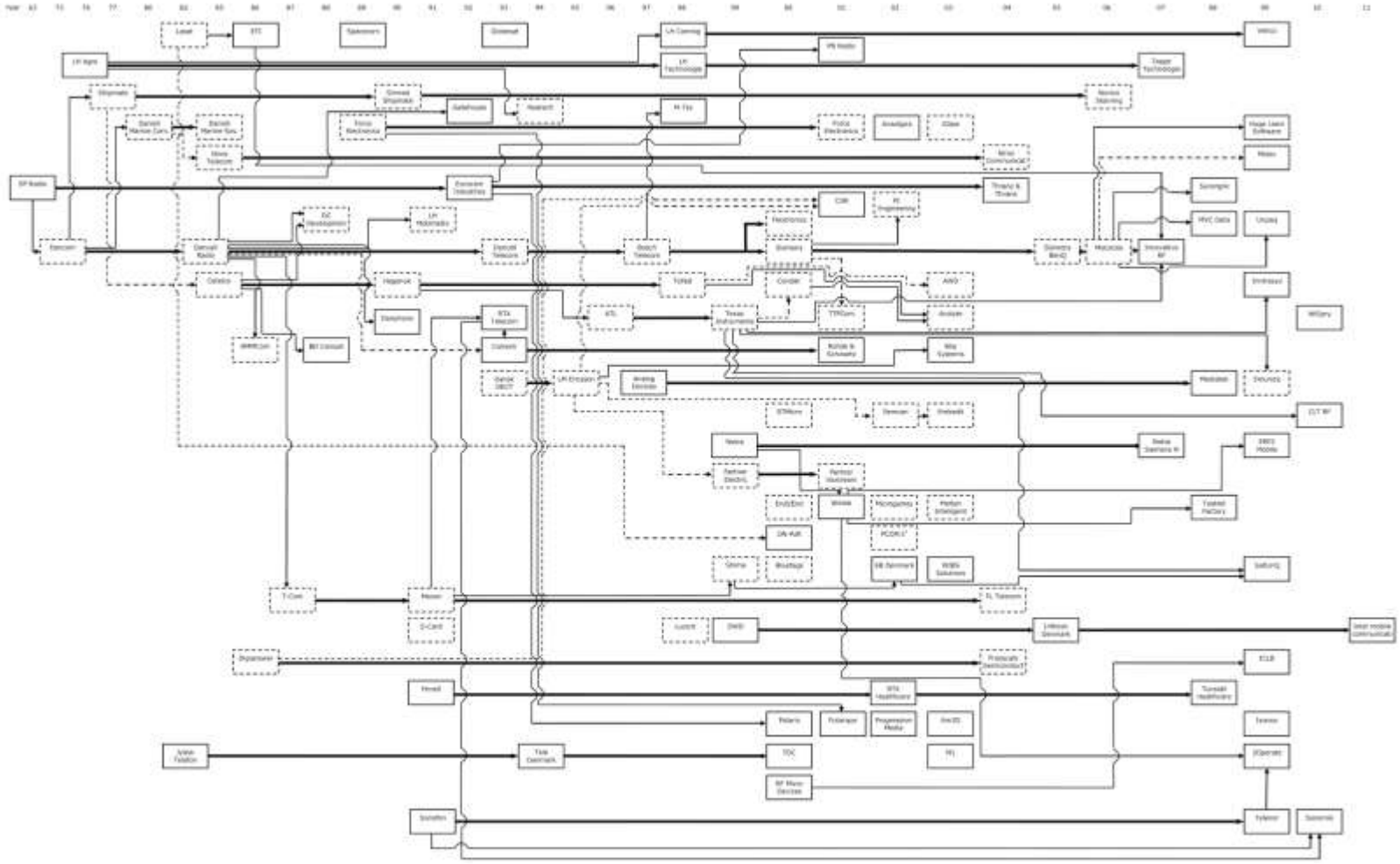
The data was collected in the following ways. First of all, the archives from earlier studies were used to identify cluster firms and the early history. This includes newspaper clippings, company reports, interview transcripts, draft papers and cluster association material. The list of all cluster firms until 2003 had been compiled by DAHL et al. (2003) with the founding and exit year, the names of founders and their previous workplaces, and the main events in the history of the firm. Then, new entrants from 2003 onwards were identified by consulting the cluster association's archive on member companies and searching various online databases for newspaper articles, media reports and corporate information. With the updated list of firms, the founders of the new companies and their former employers were investigated from similar sources. Each firm has been researched thoroughly for main events including ownership changes and close-downs, mainly using online sources, but also by formal and informal interviews.

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 work on the cluster (DALUM, 1993, 1995, 1998; DALUM *et al.*, 1999; PEDERSEN, 2001; DALUM *et al.*, 2002). The recent numbers are collected from diverse corporate databases, but since not all firms are covered by those databases, newspaper articles and media reports were used to find the numbers that are missing.

3.2. . The genealogy of the cluster

The genealogy of the wireless communication cluster until 2011 summarizes the development of the cluster (see figure 1). Fine arrows between firms show that one or more employees from existing firms established spinoff firms. Dotted arrows represent parent spinoffs where the 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 a dotted box have exited.

Figure 1 The genealogy of the cluster



4. The wireless communication cluster in North Jutland

The cluster 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, 2294 employees, a university and a cluster association.[i]

In the early years of development, the relations among the firms could be explained by competition and "production-chain-like-character" (REINAU, 2011, p. 296). Later on frequent job change within the cluster and the technical educations provided by local university encouraged the engineers to build personal relationships with former colleagues and fellow students, which then induced a high level of knowledge diffusion via the informal networks (DAHL and PEDERSEN, 2004). The university also played a role in promoting interaction among employees and firms by organising research projects that helped build relationships and trust between the participants, which then contributed to informal knowledge sharing afterwards (ØSTERGAARD, 2009). Lastly, the firms were also interconnected through the cluster association. The cluster association created a platform for dialogue and collective actions among the cluster firms and the university.

The cluster has experienced three periods of major external disruptions: 1) from 1988-92, following the shift of the mobile communications standard from the Nordic NMT standard to the European GSM standard; 2) from 2000-3, when the European standard shifted to a world communications standard, and the telecommunications industry was in turmoil following the 3G spectrum auctions and the dot-com crisis; and 3) from 2007-9, during the financial crisis, the new standards, and the introduction of Apple's iPhone and the Android smart phones and new business models. The shifts in standards were not unexpected disruptions, but they were an immense technological and market challenge that disrupted the cluster and the entire industry, see Table 1 for more details. The next sub-section investigates in more detail how the disruptions affected the cluster and how the firms reacted, while the following sub-sections analyse the evolution of the number of firms and employees in the cluster.

4.1. Disruptions of the cluster in its history

The emergence of the wireless communication cluster (1960-80s)

The history of the cluster (named NorCOM) started with the success of the leading producer of maritime communication equipment, S.P. Radio located in a peripheral region with half a million inhabitants that was characterised by traditional industries, such as agriculture, food, fishery, tourism, textiles, tobacco, and metal manufacturing. The company started producing radio communication equipment for maritime use for small and medium-sized vessels in the early 1960s with huge success. A couple of successful local spinoffs sprang up from S.P. Radio in the 1970s. In 1973, three engineers from S.P. Radio established the

first spinoff company, Dancom. It 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 radiophones for maritime use.

In the 1980s, a range of next-generation spinoffs came from Dancom (restructured and renamed Dancall Radio in 1983) and Shipmate. These companies diversified into the related area of mobile communication equipment, which was led by the introduction of the common Nordic standard for mobile telephony (NMT)[ii]. Inheriting capabilities from the parent companies, the spinoffs were well-equipped for this diversification. One example of next-generation spinoff is Cetelco, which was established as a parent spinoff by Shipmate. 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 cluster, and the majority of those were spinoffs.

The first disruption (1988-1992) and the result (1990s)

In the late 1980s, the European telecommunication operators decided to create a pan-European system (GSM) based on digital technology. This new generation (2G) became the first technological disruption that the cluster faced. The GSM networks allowed for semi-global roaming, which created a larger market, but also attracted new entrants. Thus, the cluster firms faced both increased technological complexity and international competition. 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 Aalborg University. DC Development succeeded and its parent companies were among the first to produce a GSM phone. Other firms in the cluster followed other strategies; for example, Maxon decided to continue to make 1G phones and then moved into 2G later on when the technology had matured slightly.

In the 1990s, more spinoffs were founded based on GSM technologies, producing mobile phones, chips and other supporting technologies. This development, however, was not smooth, since several companies in the cluster faced severe financial and technological problems following the shift from 1G to 2G. Most of the troubled companies and laid-off employees were taken over by other companies in the cluster, which shows that the cluster was resilient in this period. For example, Cetelco, suffering from financial constraints, was acquired by Hagenuk in 1990. Dancall also experienced financial trouble, as their newly developed GSM phone was not competitive because of its high price. Furthermore, 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.

Despite these financial difficulties, the total employment in the cluster increased constantly from 1992. By the end of the 1990s, the number of firms in the cluster had more than doubled, mainly due to entry by spinoffs. Among the 20 entrants in the cluster, seven were entrepreneurial spinoffs and six were parent

spinoffs of foreign companies such as Analog Devices, Lucent, Infineon, and Nokia. In this period, the ownership structure of the cluster changed significantly, as many foreign MNCs entered the cluster to access the competencies of local development engineers (LORENZEN and MAHNKE, 2002).

In Denmark, the wireless communications industry was mainly located in North Jutland and in Copenhagen, where the latter mainly consisted of a very large R&D unit of Nokia (employing more than 1,200) and a series of smaller firms. In North Jutland, the firms and the local university had formed a cluster association in 1997 and were increasingly visible. The cluster accounted for approximately 2.6 per cent of the total regional private sector employment in 2000, but it had become an important part of the regional identity. The location quotient of manufacturing of telecommunications equipment in North Jutland was more than five in 2000 (PEDERSEN, 2005).

The second period of disruptions (2000-2003)
–economic recession and technological disruption

The cluster experienced an external shock in the early 2000s when the telecommunication sector was hit by stagnating sales after the burst of the dot-com bubble. After this economic shock, the foreign 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 foreign MNCs, and some engineers even established their own companies. When Telital closed down in 2002, some employees joined new parent spinoffs established by two foreign companies. Nokia decided to move its R&D unit to Copenhagen in 2001, and former employees established Wirtek. Some local firms were also affected by this crisis and closed down. Despite the downsizing and exits, the number of companies grew, as there were many new companies entering the cluster. In terms of the wider economy, the economy was in a recession in the beginning of 2001, followed by slow growth in 2002 that increased the regional unemployment rate by less than 0.5 percentage points. The ICT sector employment also decreased slightly from 8,700 to 8,200 from 2000-2. The cluster accounted for half of the employment in the regional ICT sector.

In a report from 2002, some of the managers for foreign MNCs complained about the lack of local decision-making power in deciding R&D strategies (DALUM and PEDERSEN, 2002). Others feared that distance to end-users and lack of knowledge related to production might become a problem. Many of the foreign MNC subsidiaries were dependent on single customers or on internal sales. The shift from 2G to 3G, the technological disruption, also posed a threat to the cluster. The standardization process for 3G had become global planning to create a global standard, bringing about intense global competition. The complexity of the technologies and the pressure on time-to-market had also increased. The firms in the cluster had various strategies. Some firms were initially active in 3G research (e.g. L.M. Ericsson, which

closed down the unit in the cluster in 2003), and others decided to adopt wait-and-see approach to the development. 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 affected its adaptive capabilities negatively.

The impact of the second wave of disruptions started to show in 2004, as many firms closed down or downsized, while there were no new entries. One of the big companies, Flextronics, closed down with 500 employees in 2004. The headquarters in Singapore decided to move the production to lower-cost locations. The close-down was considered a tragic event and marked the end of mobile phone manufacturing in Denmark, but the overall R&D employment was stable in the cluster, as the main layoffs were of low-skilled production workers.

The third period of disruption (2007-2009)
–technological disruption and economic recession

The introduction of the iPhone and Android-based smart phones in 2007 disrupted the industry and resulted in a significantly decreased demand for traditional mobile phones. These innovations, coming from the computer software industry, initiated a JOVANOVIC and MACDONALD (1994) type of industry shakeout that completely changed the industry and led to the demise of the dominant firms like Nokia, Motorola and SonyEricsson that accounted for 60 per cent of the market in 2007. In addition, the financial crisis from the second half of 2008 and the following economic crisis decreased the general demand. From 2008-10, the Danish gross domestic product shrank with almost 8 percent and the unemployment rate doubled from three to six per cent. The effect on North Jutland region was similar to that on the rest of the country.

These technological and economic disruptions posed serious threats to the cluster. As a result, two central players in the cluster, Motorola and Texas Instruments (TI), ceased their activities in the cluster in 2009. The entry of Apple and other new competitors made Motorola's market share drop from 14.3 per cent in 2007 to 4.8 per cent in 2009. Motorola's Aalborg division had focused on development of new mobile telephones and production planning until the headquarters reduced the number of newly developed models, and eventually closed its European mobile-phone divisions. TI suffered from focusing on chipsets for 2G phones instead of 3G phones, and ended up closing most of its European divisions. Motorola and TI had to lay off 275 and 75 employees respectively, consisting mainly of highly skilled R&D engineers. Unlike former instances in which foreign MNCs had laid off many engineers, this time the cluster could not take in all the released talent. This resulted in workforce migration to other regions and to other industries. It seems that the cluster was not able to adapt to this major crisis.

4.2. The role and actions of the local university and the cluster association

Aalborg University has been very influential for the development of the cluster. Since the university was established in 1974, its main role has been to supply highly-skilled graduates. Although the indirect transfer of knowledge via graduates has been the most substantial role of Aalborg University, direct research transfer also occurred. Center for Personal Communication (CPK), established in 1993 and supported by the Danish Council for Technical Scientific Research, played an important role in this type of knowledge transfer as this center was established to focus on basic research in radiocommunications technology and speech recognition. CPK had several research projects involving both the researchers at the university and the employees in the cluster. The research effort in the field was followed by the establishment of the large research unit Centre for TeleInFrastructure (CTIF) in 2004.

During the first disruption, the university contributed to the development of GSM competences, when DC development was established. Since the establishment of CPK, the center organized research projects aiming at developing other related technologies together with the cluster firms and the leading foreign firms in the industry. However, when the technology shift from 2G to 3G took place, the fundamental technologies for this new system were mainly developed in the other parts of the world. 3G research has been conducted at the university, but it did not have the same impact in the cluster as previously. One could argue that, during the second disruption, the university, as a source of new knowledge, failed to provide timely input for firm innovation. Realizing the need to develop new competences for the next generation of wireless communication technologies, CTIF has since initiated research projects for the upcoming 4G technologies with the participation from local firms and leading firms located abroad.

The cluster association, NorCOM, started in early 1997 as a club of firms and knowledge institutions and was formally founded as association with a board of directors in January, 2000. The mission of NorCOM was to improve and expand the scope of business opportunities, technological development and innovation in the cluster. Internally, NorCOM provided a meeting place for the cluster firms to discuss some issues within the cluster and to network with other firms. Externally, it placed effort in promoting the cluster so it is visible to the external environment as a cluster with strong expertise in wireless communication. More specifically, NorCOM organized industry-specific activities such as symposia, recruiting events, and plenary sessions.

As more foreign MNCs located their subsidiaries in the cluster by acquiring local firms, the share of foreign firms in the cluster increased, but they were not as keen on keeping the membership in the association as local firms (REINAU, 2011). The local firms were small in their size and therefore needed the brand of NorCOM in doing their business. On the other hand, foreign MNCs did not see the necessity to be a part of the association as they already have strong brands. Additionally, some MNCs in the cluster were direct competitors to each other, which made them reluctant to participate in the joint action, especially on technology development. Therefore, the membership in the association decreased over time

and the formal linkage of firms through association has weakened as well. The changed dynamics among firms in the association over time could have inhibited them to pursue efficient joint action during the crises. The decline of the cluster also affected NorCOM. It could not keep its specialized profile and it merged in January 2009 with the local industry association for the broader ICT sector.

4.3. Overview of the cluster in growth, sustainment and decline

The effects of the disruptions are also present in the data on employment and number of firms. Figure 2 shows the change in the population and the number of entries and exits. The number of firms had increased steadily until 2003, as there were very few exits before then, and plenty of entries. Then, after the second disruption, between 2004 and 2006, the cluster started to show signs of decline; there was no entry at all, while firms continued to exit. There are several acquisitions and reconstructions in this period which are not counted as new entry. A decrease in new-firm formation is also observed in the Cambridge cluster in its declining phase around 2005-6 (STAM and GARNSEY, 2009). In 2009, entries peaked, as 10 new firms were established. The majority of these were founded by former Motorola and TI employees. However, the survival of these entrants is questionable. Among eight spinoffs, four have founders with a regular job other than the start-up. Moreover, the majority of the new firms have no employees except the founders and most of them do not show employment growth.

Figure 3 shows the change in the number of employees in the cluster. The declining trend is apparent from 2004. Following the second disruption, total employment decreased slightly from 2000 to 2002, but increased again in 2003. From 2003, the number decreased drastically until 2005, as many firms downsized and exited in this period. Except for 2006, the number of employees continued to decline until 2010, when the number increased by merely 24. Figures 2 and 3 reveal the cluster life cycle with a long emergence phase followed by a growth phase and a short sustainment phase (2000-3 in the employment data). It could be argued that the sustainment period last until 2007 despite the decline in the number of firms and employees, because the qualitative description of the cluster suggest that it is during the third period of disruptions that the large companies close down, the technological heterogeneity and diversity shrinks, R&D employees leave to non-cluster industries and the identity as a wireless communications cluster is being challenged.

[Insert figure 2 about here]

Figure 2 Total population and entry and exit of firms in the cluster

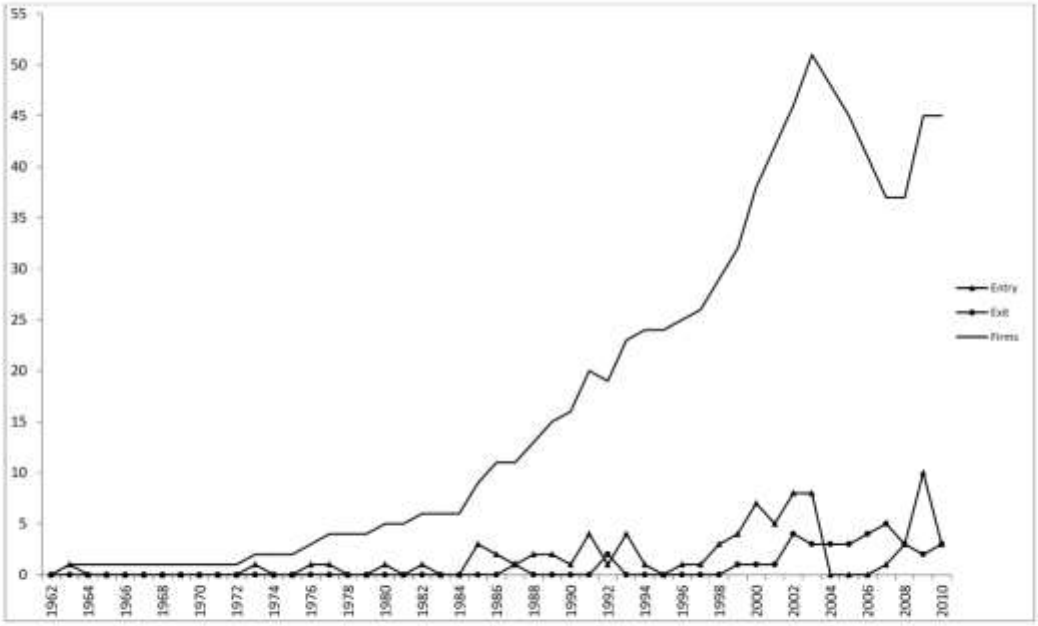
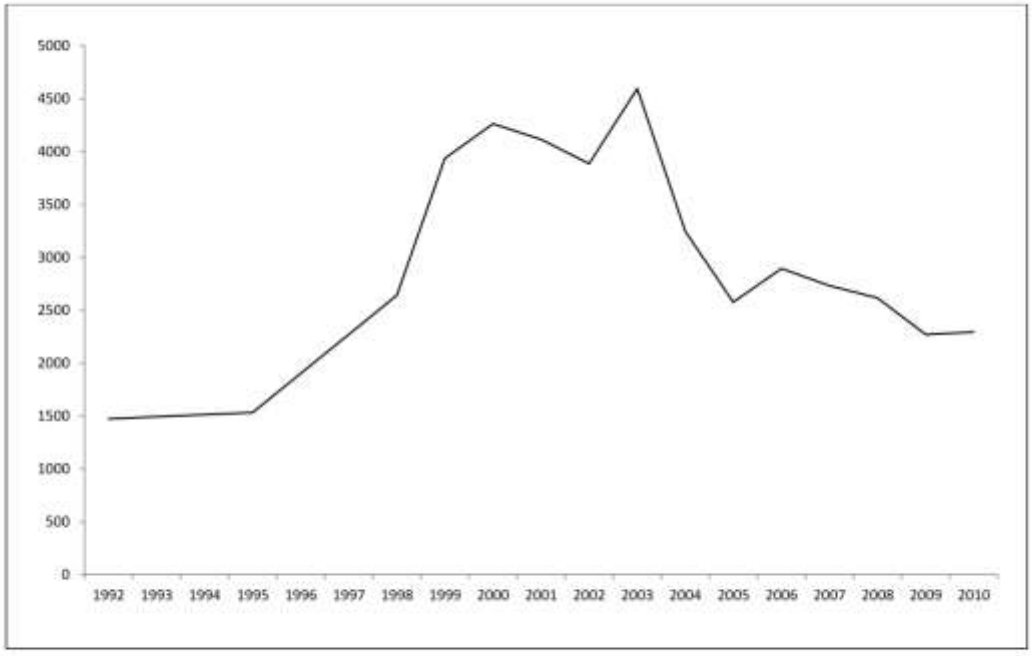


Figure 3 Employment in the cluster



4.4. What changed the adaptive capabilities of the cluster and made the cluster decline?

The decline of the cluster is clearly linked to the lack of adaptability in the third period of disruptions. Table 1 shows the three periods of disruptions that the cluster faced, the dynamics within the industry and cluster at the time of disruptions, the impact of the disruptions, and the change observed after the disruptions.

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

	1988-1992	2000-2003	2007-2009
External disruptions/ Threats	Technological disruption • New standard: 1G (NMT) to 2G (GSM) - From analogue to digital - From Nordic to European - Increasing complexity	Technological disruption • New standard: 2G (GSM) to 3G (WCDMA/UTMS) - From European to worldwide standards - Increasing complexity • Tele service providers and 3G spectrum auctions Economic recession • Dot-com crisis	Technological disruption • New standard: 3G (WCDMA/UTMS) to 4G (LTE) - Importance of data transmission • Introduction of smartphones - Convergence with computer industry Economic recession • Financial crisis
Industry dynamics - Demand - Competition - Structure - Technology	• Larger market spanning the whole Europe • Increasing demand • Increasing competition • Entry by large electronics 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 industries • Large scale production • Intense technology development • Shorter product life cycle • Increasing modularisation	• New entry : Apple, Google, and Microsoft • New operating systems • Increasing importance of software products • New path in technology development • Decline of old incumbents such as Nokia, Motorola, and Sony • Emergence of new leaders: e.g. Apple, Samsung, • Emergence of new markets: e.g. China, India
Cluster dynamics - Structure - Strategies - Policy	• Around 15 firms in the cluster • Joint venture 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 • Increasing number of MNCs in the cluster • Specialisation in different components of mobile phones • CTIF established at Aalborg University to focus on 4G technologies • Seedbed firms exited • Fragmented strategies of firms led to lack of 3G competences in the cluster - Attempt on collaboration on 3G failed - Others 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 • Aalborg University focusing on 4G technologies • Entry by spinoffs from exiting firms
Result - Evolution	• Increasing number of firms • Troubled firms acquired by MNCs • Laid-off employees were hired by other firms in the cluster. • Adaptive capabilities were strong 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 • Adaptive capabilities were weakened 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 • Limited adaptive capabilities - Firms that generated many spinoffs closed down - Survival of new firms is also in doubt • Cluster decline

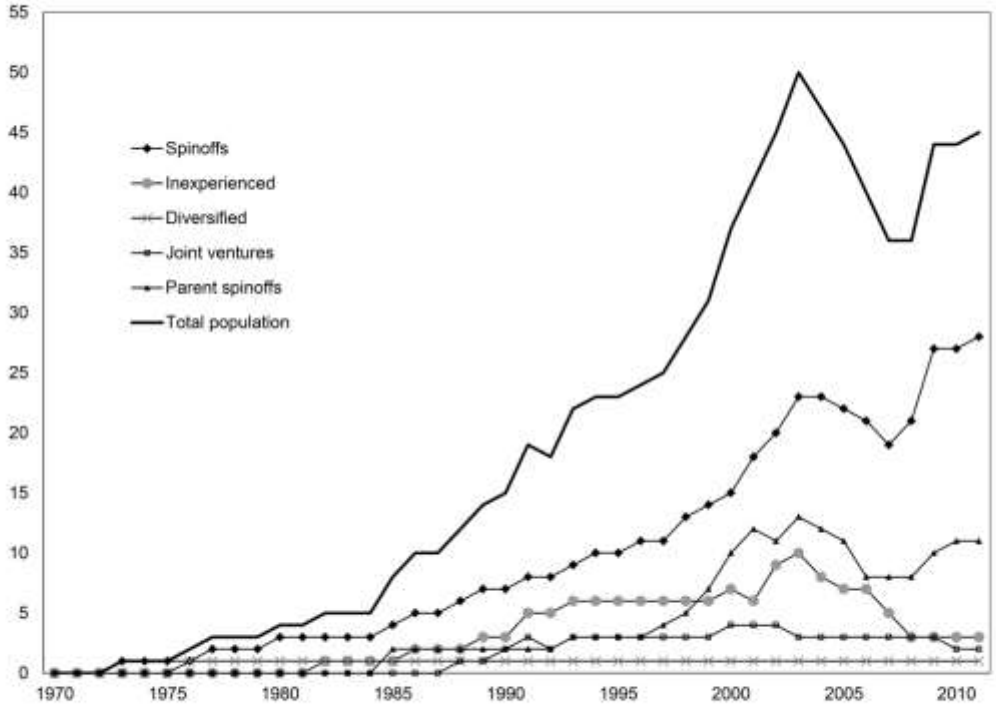
The most important factor that changed was the presence of relevant technological competence at the time of transition from one generation of system to another. During the first transition, two firms formed a successful joint venture in order to develop the new technologies. The technological heterogeneity broadened as some companies founded a joint venture to focus on cordless phones while others went into related fields. This broadening of the market and knowledge base must have increased the cluster's adaptive capabilities during the growth phase as suggested by MENZEL and FORNAHL (2010).

However, when 3G emerged, the development of basic technologies did not take place in the cluster to the same degree as with previous standards. Collaboration efforts initiated by some firms did not succeed. Furthermore, MNCs decided that R&D in 3G technologies should take place elsewhere. When TI acquired a cluster firm in 2002, it simply closed the 3G technology division. The 3G technology, which became a major disruption, was vastly more complex than 2G and required huge investments in R&D that only large companies could afford. The rise in innovations thus increased the entry barriers and put pressure on less efficient innovators (KLEPPER and SIMONS, 2005). Consequently, the technological competencies within 3G were mainly developed in other parts of the world. This technological lock-in was initially not a problem, because 3G had a slow start and initially seemed unsuccessful, while 2G products still sold well. A few years later, smart phones boosted 3G sales. Facing this disruption, the lack of 3G competencies became a major problem. In addition, the innovations introduced by Apple and Google disrupted the entire industry and increased the pressure for firms to innovate or implement the disruptive innovation (e.g. switch to the Android system) or simply exit.

The technological lock-in did not only lower the opportunities for new firms to emerge when the technology standard shifted, but it also deteriorated the competitiveness of incumbents by limiting intrapreneurial opportunities within firms, which eventually led to the exit of some important players in the cluster.

Another factor that might have affected the adaptive capabilities after the second disruption is the exit of firms that had created many spinoffs. Looking at the change in the population of firms by entry type (see figure 4), it can be seen that entrepreneurial spinoffs largely account for the development of the cluster over the whole time period. The spinoff process was especially important in the emergent phase, which is also seen in other studies (KLEPPER, 2010).

Figure 4 Firm population by entry type



These companies became seedbeds for many spinoffs later on, and were crucial for further development of the cluster as these function as training grounds for entrepreneurs who gain relevant capabilities and routines from the parent companies. The exit of these firms possibly affects the level and quality of entrepreneurship in the cluster in the future. This might explain the low level of entry from 2004-10.

The next factor that changed was the concentration of foreign MNCs in the cluster. After the first disruption, some local companies were acquired by foreign firms due to financial problems. Moreover, more foreign MNCs entered the cluster in the 1990s, as they were attracted to its competence level. Initially, this increased the heterogeneity, creating global links and financial strength. However, the high concentration of foreign firms proved to be a weakness during the times of crisis. Many subsidiaries did not have much influence on strategic decisions made by the MNCs' headquarters and were also limited in their search for innovation (REINAU, 2011). Furthermore, when the industry was in crisis, many of the foreign MNCs relocated their development activities to bigger R&D centres. These negative effects of MNCs in clusters is in line with findings in the literature (BIRKINSHAW and HOOD, 2000; GÖRG and STROBL, 2003; CANTWELL and MUDAMBI, 2011).

5. Conclusions and discussion

Regional clusters are constantly exposed to external disruptions from changes in the industry and the market. A cluster's ability to adapt to these changes determines the evolution of the cluster after such disruptions. This paper analyses the process of cluster decline, which has been a rather neglected subject in cluster research. An in-depth case study on a wireless communication cluster shows that changes in the cluster's adaptive capabilities are important in understanding how and why a well-functioning cluster turns into a declining cluster following several periods of disruption. What is interesting in the NorCOM story is that these adaptive capabilities can change over time, and that a once highly adaptive cluster can decline if some factors diminish its ability to renew itself.

The quantitative data points toward the signs of decline following the second period of disruption, while the qualitative signs of decline becomes evident in the third period of disruption, where large MNCs leave the cluster, the heterogeneity and diversity shrinks and highly skilled employees leaves the cluster. Furthermore, the strong identity as a wireless communications cluster becomes challenged as the dominant firms close down and in particular with the closing of the cluster association when it merged into a broader association for the regional ICT sector. The longitudinal study on the cluster examined here enhances the understanding of the factors that influence its development over time.

The major force that affected NorCOM's adaptive capabilities was lock-in. The fact that the firms were not able to develop the newly dominant technologies in the industry implies that there was a technological lock-in. Cognitive lock-in among cluster firms have brought about the technological lock-in, as they focused on further development of the already-existing technological competencies in 2G instead of being active in developing new technologies. Organizational lock-in could be found in the operations of subsidiaries of the MNCs, where the R&D divisions in different locations had to compete against each other for headquarters' choice of new products. Sometimes, the new initiatives of local employees were turned down because they did not fit with the headquarters' overall strategy (REINAU, 2011). What happened in the cluster is also in line with the argument by MARTIN and SUNLEY (2006) that processes and configurations built up 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, it seems that lock-in is only part of the explanation for the cluster's limited adaptive capabilities. While MARTIN and SUNLEY (2011) almost solely focus on the reorientation of existing companies (intrapreneurship) as a source of adaptive change, new-firm creation is also critical to adaptability. One way for a cluster to reorganize itself and recover is entrepreneurship (MENZEL and

FORNAHL, 2010). This is proven in the case when the cluster experienced the first crisis 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 engaging laid-off employees. Silicon Valley, the Cambridge high-tech cluster, and the Ruhr area all demonstrate the importance of new firms to a cluster's ability to reorganise when facing disruptions.

In addition, the strong presence of foreign MNCs in the cluster also influenced the evolution, yet with some contradictory effects in different time periods. When the cluster was in a growing phase, many foreign firms entered the cluster to get access to its highly skilled labour. After the first disruption, MNCs did in fact save the leading cluster firms that had severe financial troubles by acquiring them. In this way, the technological competencies that otherwise were in danger of being dissolved remained within the cluster. The foreign MNCs also provided access to new markets, financial resources and knowledge (BATHELT *et al.* 2004; CANTWELL and MUNDAMBI, 2005). Entry of MNCs therefore had a positive effect on the cluster's adaptive capabilities in this period. However, during the next disruptions, foreign firm's presence proved vulnerability. They were largely reactive to changes in the industry, as they readily downsized or simply exited the cluster during the crises, proving that they are much more 'footloose' than local firms (GÖRG and STROBL, 2003). The MNCs' decision to withdraw from a location also depended on the overall performance of the company and was also affected by the severity of the third period disruptions that resembles a JOVANOVIC and MACDONALD (1994) industry shakeout. For example, Motorola suffered from a sharp decrease in its market share in the mobile phone market, which directly influenced the company's decision to exit the cluster. Some policy implications can be inferred from the above findings. In terms of creating diversity in the cluster and developing pipelines to other external actors, the attracting MNCs can strengthen the cluster's adaptive capabilities (see also MENZEL and FORNAHL, 2010; MARTIN and SUNLEY, 2011). MNCs can also takeover failing firms and preserve the activities in the cluster in the time of disruption. However, policies towards foreign MNCs should ensure that these firms are embedded in the cluster environment and maintain their commitment to the cluster over time. The existence of foreign firms clearly brings both positive and negative effects to the clusters. The footloose nature might be a challenge when adapting to a major disruption. In order to deal with these issues, policies should also direct attention to supporting the local actors in retaining the technology leadership within the cluster. For a declining cluster, policies could also be directed towards helping the laid off employees entering related industries and avoiding a chaotic decline.

The findings in this paper point to some relevant future research areas. Firstly, studies on evolution of other wireless communication clusters within the same period of time will reveal more location-specific factors that may affect the decline of clusters. Secondly, how the adaptability of a regional economy is

related to that of a 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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[i] The average age of the cluster firms is about 11.5 years. The average size in terms of employees is 51, while the average size in terms of gross profit is about 3 million euros (this figure is only available for 38 firms). 14 companies (about 30% of the cluster firms) are foreign owned and their employees account for about 66% of the total employee population in the cluster.

[ii] 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 their own. 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 competed with each other. The first-generation technology system (1G) was represented by analogue mobile systems. In 1981, the Nordic mobile telephony operators launched the first cross-national public mobile telephony system, called NMT.