NTNU – Trondheim
Norwegian University of
Science and Technology

On International Technology Diffusion

A Case Study of the Norwegian
Microelectronics Industry

Andreas Flåt Aglen
Sondre Gullord Graff

Industrial Economics and Technology Management
Submission date: May 2013
Supervisor: Arild Aspelund, IØT

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Aglen, Andreas Flåt**	Fødselsdato **21. jun 1989**
E-post **andreas.aglen@gmail.com**	Telefon **48196691**

2. Studieopplysninger

Fakultet **Fakultet for Samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Strategi og internasjonal forretningsutvikling**

3. Masteroppgave

Oppstartsdato **15. jan 2013**	Innleveringsfrist **11. jun 2013**
Oppgavens (foreløpige) tittel **On International Technology Diffusion**	
Oppgavetekst/Problembeskrivelse The thesis will focus on the international trajectory of new technologies and innovations. The intention is to investigate the role of large and small multi-nationals (INVs), industrial districts, international spillovers, and interaction modes in international technology diffusion, and to understand how the interaction of these elements incurs broader societal effects. Particular attention will be given to the understanding of how the interaction contributes to economic development. We plan to structure our thesis according to the following: - A section describing relevant theoretical concepts: We aim at giving a thorough introduction to prevalent literature within several research areas, including international new venture theory, economic development theory, industrial district theory, and international spillover theory. - A section describing our method: We will conduct a case study, identifying a distinctive technological innovation, and map its trajectory from its inception to its current situation and influences. Multiple chains of evidence will be used. - A discussion where we seek to establish a framework for understanding the participants and trajectory of intern...	
Hovedveileder ved institutt **Førsteamanuensis Arild Aspelund**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

23.08.13

Sted og dato

Student

Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

SAMARBEIDSKONTRAKT

1. Studenter i samarbeidsgruppen

Etternavn, fornavn	Fødselsdato
Aglen, Andreas Flåt	**21. jun 1989**
Etternavn, fornavn	Fødselsdato
Graff, Sondre Gullord	**09. jun 1989**

2. Hovedveileder

Etternavn, fornavn	Institutt
Aspelund, Arild	**Institutt for industriell økonomi og teknologiledelse**

3. Masteroppgave

Oppgavens (foreløpige) tittel
On International Technology Diffusion

4. Bedømmelse

Kandidatene skal ha *individuell* bedømmelse ☐
Kandidatene skal ha *felles* bedømmelse ☒

23.01.13
Sted og dato

Hovedveileder

Andreas Flåt Aglen

Sondre Gullord Graff

Originalen oppbevares på instituttet.

NTNU
Det skapende universitet

MASTERKONTRAKT

- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Graff, Sondre Gullord**	Fødselsdato **09. jun 1989**
E-post **sondre.graff@gmail.com**	Telefon **47644872**

2. Studieopplysninger

Fakultet **Fakultet for Samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Strategi og internasjonal forretningsutvikling**

3. Masteroppgave

Oppstartsdato **15. jan 2013**	Innleveringsfrist **11. jun 2013**
Oppgavens (foreløpige) tittel **On International Technology Diffusion**	
Oppgavetekst/Problembeskrivelse The thesis will focus on the international trajectory of new technologies and innovations. The intention is to investigate the role of large and small multi-nationals (INVs), industrial districts, international spillovers, and interaction modes in international technology diffusion, and to understand how the interaction of these elements incurs broader societal effects. Particular attention will be given to the understanding of how the interaction contributes to economic development. We plan to structure our thesis according to the following: - A section describing relevant theoretical concepts: We aim at giving a thorough introduction to prevalent literature within several research areas, including international new venture theory, economic development theory, industrial district theory, and international spillover theory. - A section describing our method: We will conduct a case study, identifying a distinctive technological innovation, and map its trajectory from its inception to its current situation and influences. Multiple chains of evidence will be used. - A discussion where we seek to establish a framework for understanding the participants and trajectory of intern...	
Hovedveileder ved institutt **Førsteamanuensis Arild Aspelund**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

23.2.13
....
Sted og dato

....
Student

....
Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

SAMARBEIDSKONTRAKT

1. Studenter i samarbeidsgruppen

Etternavn, fornavn **Aglen, Andreas Flåt**	Fødselsdato **21. jun 1989**
Etternavn, fornavn **Graff, Sondre Gullord**	Fødselsdato **09. jun 1989**

2. Hovedveileder

Etternavn, fornavn **Aspelund, Arild**	Institutt **Institutt for industriell økonomi og teknologiledelse**

3. Masteroppgave

Oppgavens (foreløpige) tittel **On International Technology Diffusion**

4. Bedømmelse

Kandidatene skal ha *individuell* bedømmelse ☐
Kandidatene skal ha *felles* bedømmelse ☒

23.01.13
Sted og dato

Hovedveileder

Andreas Flåt Aglen

Sondre Gullord Graff

Originalen oppbevares på instituttet.

Summary

The study identifies two knowledge networks through which firms can identify and absorb new knowledge. One such knowledge network is nationally oriented, and constitutes of commercial and non-commercial actors situated in a domestic environment. The other network is internationally oriented, and allows national firms to tap into knowledge pools that reside in foreign countries. Research traditions have investigated these networks separately; cluster theory in particular has gotten immensely popular for its emphasis on the local knowledge network. We derive a model of international diffusion that bridges the two knowledge networks, and investigate how the process of international technology diffusion relates to the competitiveness of national industries. The model's appropriateness is tested through a case study of the birth and growth of the Norwegian microelectronics industry. The findings suggest that firms depend on different knowledge networks through different phases of industry development. When present in international markets, firms prioritize international knowledge relations in order to be responsive to technology trends. This insight challenges the cluster theorists' emphasis on the importance of locality, and implications for management and policy makers are discussed.

Sammendrag

Denne rapporten retter fokus mot to ulike kunnskapsnettverk som bedrifter kan benytte seg av for å tilegne seg ny kunnskap. Det første er det nasjonale kunnskapsnettverket, som er forankret gjennom ulike nasjonale aktører, både de med og de uten kommersielle intensjoner. Det andre nettverket er rettet internasjonalt, og muliggjør for nasjonale bedrifter å ta til seg kunnskap fra andre land. I forskningen har disse to kunnskapsnettverkene tradisjonelt blitt analysert separat; klyngeteori har vekt spesielt stor interesse for sitt fokus på viktigheten av lokale kunnskapsnettverk. I denne rapporten utarbeider vi en modell som knytter de to kunnskapsnettverkene sammen, hvorigjennom konkurransekraften til nasjonale industrier blir analysert i lys av teknologidiffusjon på tvers av landegrenser. Gyldigheten til denne modellen er testet gjennom en case studie av livsløpet til den norske mikroelektronikkindustrien. Funnene indikerer at viktigheten av de to kunnskapsnettverkene varierer betydelig gjennom ulike faser av industriens fremvekst. I faser hvor bedrifter har betydelige aktiviteter i internasjonale markeder, tenderer bedriftene til å prioritere internasjonale kunnskapsrelasjoner, fremfor de nasjonale, for å være mest mulig responsive til teknologitrender. Den innsikten dette gir oss om kunnskapsnettverk utfordrer klyngeteoretikernes fokus på det lokale, og medfølgende implikasjoner for bedrifter og andre beslutningstagere i samfunnet blir diskutert.

Preface

This thesis concludes our Master's program in Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU). We have chosen to specialize in Strategy and International Business Development.

The study is an attempt at bridging theories on technology diffusion *across* and *within* nations respectively. As a way to test the derived theoretical model, a case study is conducted of the Norwegian microelectronics design industry.

The study is presented through eight sections. Part 4 is a chronological depiction of the rise of the Norwegian microelectronics design industry, and can be read entirely on its own.

We are grateful for all the contributors that have helped us in our research. We would like to thank professor Snorre Aunet at Department of Electronics and Telecommunications at NTNU for his guidance in technical aspect in the early parts of the study; professor Tage Koed Madsen at the University of Southern Denmark for his enthusiasm in the case and case methodology; the ten highly benevolent interviewees who were outspoken and willing to share of their insights and knowledge, enhancing the quality of the study; and last but not least, our supervisor Arild Aspelund, for contributing to our progress by asking questions rather than providing answers.

Table of Contents

Table of Figures

Table of Tables

Part 1: Introduction

Industries are increasingly global. An interesting pattern is that companies that compete against each other often can be located in different countries across the world. The largest players in the automotive industry are located in the US, Germany and Japan. The world's largest producers of insulin have headquarters in Denmark, the US and France. The dispersed competitors follow each other's moves closely, even at large spatial distances.

Often these global firms improve their product offerings by integrating technologies that originated elsewhere in the world. The significance of such new innovations could range anywhere from small incremental improvements, to great scientific breakthroughs. To continue on the examples of the automotive and insulin industry: The three-point safety belt was invented by Nils Bohlin in Sweden in 1958, and before long it was standard equipment in all cars produced. Insulin was first extracted by researchers at the University of Toronto in Canada in 1921, with commercial production starting a few years later. Because only a handful of countries stand for most of the world's creation of new knowledge, technology diffusion across borders is highly important for global economic development (Keller, 2004).

Then there is a second pattern of industrial organization, which takes place on the local level. Across the world, you can find geographical regions that host several of the world's most competitive companies within specific industries. Silicon Valley in California, US, is a well-known example; it is the home to many of the world's largest hi-tech firms. Similarly, a large number of world-leading pharmaceutical companies are situated in and around Copenhagen, Denmark. Companies in such regions often learn from one another about changing technology and market conditions, with the result of fostering dynamic cluster environments (Saxenian, 1996).

The two observed patterns coexist; we believe that they are indeed complementing each other. When they are combined, the emerging system is one of international technology diffusion. The spread of new technology is ensured through technology diffusion *across* national borders, allowing for firms across the world to integrate features that originated abroad into their offerings to improve competitiveness. Then, technology diffusion happens *within* national borders, allowing for competitiveness of *several* national companies with the potential of building sound national industries.

Few attempts have been made at bridging technology exchange processes within and across national borders (e.g. Bathelt, Malmberg and Maskell, 2004). Instead, each process has built its own legion of avid supporters, and this has given rise to two bodies of literature with few points of intersection. On one side, cluster theorists embrace the idea that geographical agglomeration of industries is the most advantageous way to organize industrial activities. In this field, Michael Porter's (1990) contribution, *The Competitive Advantage of Nations*, has been immensely popular, and his analyses have directed much of the research focus over the last two decades. One the other side, researchers in the field of international trade theorize on the importance of channels for knowledge exchanges across border (e.g. Grossman and Helpman, 1991; Coe and Helpman, 1995).

In the center of the two distinct processes, are the technology firms. They are the ones that seek competitive advantages in their particular industry; they are the ones that need to maneuver in a landscape where prioritization of limited resources is an ongoing concern. Where to seek new knowledge, what strategic alliances to promote, and at what costs?

If the companies seek advice from cluster theorists, they will be told to embrace their locality, and to seek competitive advantage through leveraging the differentiators in the domestic environments (e.g. Porter, 1990; 1998). Knowledge, they'll be told, is spatially bounded, and the most efficient way to identify and absorb such knowledge is by co-locating with relevant knowledge sources (e.g. Audretsch and Feldman, 1996; Audretsch, 1998). According to international trade proponents, the focus must be on tapping into valuable knowledge bases that resides abroad (e.g. Grossman and Helpman, 1991).

Adding policy makers to the debate adds another dimension of complexity. Promotion of national industries lies in the heart of industrial policies in most countries, and ensuring competitiveness of national companies becomes a primary goal. Again, the two sides of the debate provide policy makers with two different sets of tools: From cluster theorists, they will hear that the securing of the right domestic factor conditions is highly important (Porter, 1990). From international economists, integration in world markets is key: Allow for foreign firms to invest in your country (e.g. Branstetter, 2006), and promote national firms in their export endeavors (e.g. Bye, Fæhn and Grünfeld, 2008).

It is the duality of local versus distant that lies in the center of this study. Basically, we seek to investigate international and domestic knowledge networks, and understand their distinctive roles in international technology diffusion. We ask: How to maneuver in an environment where both local and distant knowledge relations can be considered choices? What knowledge networks are antecedents to competitiveness of national firms and development of national industries? Finally, how does in fact technology diffuse across and within national borders, or rather; what are the mechanisms of the knowledge exchanges?

The subject matter is complex, and we believe that the best way to go about answering these questions is by conducting a case study. Exemplified by the depiction of a successful national industry, we will establish a comprehensive framework for understanding and discussing international technology diffusion. Our case of choice is a subsection of the Norwegian microelectronics industry, comprising of firms that are highly competitive in international markets.

In a recent article in the Norwegian technology periodical *Teknisk Ukeblad*, the microelectronics industry was referred to as "Norway's unknown billion kroner industry" (Hamnes and Valmot, 2012), with companies that had succeeded "against all odds". Indeed, the evolvement of the industry has never been described in depth, and we consider it a parallel goal to provide a comprehensive document about the pivotal events and key achievements. We intend to conduct an extensive study, using first-hand accounts and multiple sources of evidence, in order to understand the knowledge antecedents to the national industry's birth, growth and competitiveness.

Part 2: Theory

2.1 Technology and economic development

Easterlin (1981, p.1) opened his article "Why Isn't the Whole World Developed?" with the following comment: "The worldwide spread of modern economic growth has depended chiefly on the diffusion of a body of knowledge concerning new production techniques". "Body of knowledge", as Easterlin uses it, is also referred to as technology, and is widely regarded as one of the primary drivers of economic development, both historically and at present. The words *knowledge* and *technology* will be used interchangeably throughout this thesis, with the common feature that they describe an idea of how to translate input into productive value (Romer, 1990).

Traditionally, economic growth has been modeled as a process in which capital and unskilled labor are the only inputs, and where technology defines the output potential for any combination of these (Solow, 1956). It follows that technological development becomes the long-term driver of economic growth, because it allows society to get greater output from the inputs that are available. However, how technological advances happen in an economic context is left unexplained by the models; they arise from external forces. One says that technology exists exogenously.

More recent economic growth models have made an attempt to include technology, or knowledge, as an endogenous variable in the aggregate production function. Such endogenous growth models argue that market incentives make economic firms act intentionally to create new technologies, which in turn drives economic growth. In order to arrive at this conclusion, Romer's (1990) contribution on how to think about knowledge as a good is important. He argues that knowledge have characteristics that are inherently different from those of the traditional production inputs.

First, knowledge is thought of as *non-rival*, meaning that it is possible for several actors to hold the same knowledge at the same time, or, as Romer (1990, p.74) writes: Knowledge has the property that "its use by one firm or person in no way limits its use by another". Conversely, capital and labor are rival goods that can only be used at one location at the time.

Second, "pure" knowledge is a good that it is difficult to exclude other actors from using. In other words, even though knowledge might be expensive to develop, the reproduction of it, once it is conceived, might be done at virtually no cost. This quality is called *non-excludability*, and it sets knowledge up as a good with increasing returns to scale. In order to ensure sufficient incentives for economic actors to invest in the development of new knowledge, it is important to enforce partial excludability through legal arrangements such as intellectual property rights (Romer, 1990).

When knowledge is understood as a non-rival, partly excludable good, the market incentives that make firms invest in the development of new technology have important positive externality effects. This concept has been termed *knowledge spillovers*, and can be explained in the following way:

> By spillovers, we mean that (1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so required (Grossman and Helpman, 1991, p.16).

The knowledge spillover mechanism is a powerful one in understanding the process of technology diffusion: One actor, be it a corporation or a research institution, develops new knowledge. Imminently, a spillover potential is embodied in this knowledge. Other actors might identify this potential, and adopt it, with the effect of transferring knowledge from one actor to another.

Researchers have argued for a spatial dimension of knowledge externalities (e.g. Lucas, 1988; Romer, 1990). Audretsch (1998, p.21) employs a distinction between *information* and *tacit knowledge* as a way to explain this: Whereas information is "easily codified and has a singular meaning and interpretation", tacit knowledge is "vague, difficult to codify, and often only serendipitously recognized". Tacit knowledge thus requires close interaction between the source and the potential absorber in order to be understood and transferred.

While knowledge spillovers are ways for technology to diffuse that, by definition, occur without payment, knowledge transfers might also be done transactional, through legal arrangements. The question of how technology diffuses becomes a question of how actors identify and acquire knowledge, and the trajectory of the transfers between firms.

2.2 Technology diffusion system

We will attempt to establish a model for international technology diffusion, and incorporate *knowledge networks* as antecedents to knowledge transfers. Knowledge networks describe the nets of channels through which economic actors can adopt knowledge from other commercial and non-commercial actors. The actors that take part in the knowledge networks hold unique *knowledge bases*, defined as a "set of information inputs, knowledge and capabilities that inventors draw on when looking for innovative solutions" (Dosi, 1988, p.1126). Knowledge is embodied in the skilled employees of a firm, but also in the routines of firms and in the relationships between organizations and between people (Lundvall, 2007). *Absorptive capacity* refers to a firm's ability to "identify, assimilate, and exploit knowledge from the environment" (Cohen and Levinthal, 1989, p.569). In addition to acquiring knowledge externally, firms can advance their knowledge bases by developing new knowledge in-house (Giuliani and Bell, 2005).

The international technology diffusion model employs the viewpoint of a domestic economic system, whose interest is to adopt foreign developed knowledge if it can be used to increase the productivity of current economic activities. Productivity of its economic activities, furthermore, can be understood as its ability to promote firms that are competitive in global markets, following Porter's (1990) line of thought. To structure our discussion of the theoretical concepts and the subsequent case, we will define an ***efficient technology diffusion system*** as one that can be distinguished by the following:

- The presence of a distinctive technology that originated abroad
- The presence of several national actors whose products have integrated this technology as a defining feature
- Competitiveness over time for these national actors in international markets

The roles of the firms in the technology diffusion model will differ according to the scope of any particular firm's knowledge networks (through which it channels knowledge exchanges), its current knowledge base (as the potential of what the firm can channel to other actors), and its absorptive capacity (its ability to absorb external knowledge).

In the following, we will discuss variations in and characteristics of knowledge networks by distinguishing between a firm's domestic and international knowledge networks. As it has been called for by researchers (Owen-Smith and Powell, 2002; Bathelt et al., 2004), we intend to contribute by bridging the gap between research traditions that focus on either of these two distinct networks.

It is worth mentioning that there are distinct differences between domestic and international economic systems, which set them up as two different environments in which to conduct economic activity. Domestic actors are bound by the same legal frameworks, and governmental trade initiatives have a jurisdiction bounded by national borders. Cultural characteristics that relate to how economic activity is conducted are often more convergent within national borders than across them (Hofstede, 1984).

2.3 The domestic knowledge networks

A company's home base can be thought of as the location at which the company performs some core functions, be they strategic decision-making, R&D or some form of manufacturing (Sölvell and Zander, 1995). Often this location is the place where the company was first established. Within the nation's borders, the company might interact with domestic actors in a number of settings, including, but not limited to, supplier- and buyer relations, industry bodies and research collaborations.

When the firm's network of domestic firms becomes a complex entity of industries connected through vertical and horizontal relationships, it qualifies as a *cluster*, as according to Porter (1990). More specifically, Porter (1998, p.78) defines clusters as "geographic concentrations of interconnected companies and institutions in a particular field". Porter (1998, p.1) argues that national clusters must be the unit of analysis if one seeks to understand why a nation becomes "the home base for successful international competitors in an industry". We will use many of the insights of Porter's cluster models to understand the domestic knowledge system, and its implications for efficient technology diffusion.

Porter's (1990; 1998) cluster theories have enjoyed immense interest among policy makers and researchers alike. In particular, his "diamond model" (Porter, 1990) has been highly influential in stating out the fundamental factors that support the clusters' growth and competitiveness. This "diamond model" suggests that there are "four broad attributes of a nation that shape the environment in which local firms compete that promote or impede the creation of competitive advantage" (1990, p.71). First, there must be sufficient factor conditions, or inputs such as skilled labor and infrastructure, that are necessary in order to compete in any industry. Skilled labor, for example, might be supplied through relevant programs at public and private educational institutions (Porter, 1990). The second attribute relates to the domestic demand for the industry's products or services: Demand from sophisticated domestic buyers reinforces the national advantage of an industry (Porter, 1990). Third, clusters benefit from a presence of related and supporting industries that are internationally competitive themselves. Finally, Porter (1990) names characteristics related to firm strategy, structure and rivalry as important, because they are national conditions that are decisive for how firms are operating and established. One such condition is domestic rivalry, which Porter (1990; 1998) argues is highly stimulating for increased productivity and competitiveness.

Following the "diamond model", we propose three distinctive elements that should be expected in a domestic industry with actors that are competitive in international markets:

Proposition 1a: An efficient technology diffusion system is characterized by the following:

- *i) Domestic supply of labor with relevant education*
- *ii) Significant domestic demand conditions*
- *iii) Competition between domestic firms*

In a long tradition of inquiries into the success of industrial districts, other researchers have emphasized other fundamental attributes. Piore and Sabel (1984, p.266) highlighted the importance of the community around which economic activity is conducted, and suggested that "it is doubtful whether regional conglomerations can survive without community ties, be they ethnic, political, or religious". Saxenian (1996) also emphasized the cultural aspects of regional agglomerations, and argued for a system where production is embedded in the regional institutions and social structures through greater interdependence among firms and greater interaction among individuals.

Significant efforts have been directed towards conceiving of the cluster concept as a localized knowledge system, where it is easier to identify new knowledge due to the close proximity to knowledge sources (e.g. Porter, 1990; Saxenian, 1996; Audretsch, 1998). This feat of regional agglomerations was first noted by Marshall (1890, p.271) who investigated trade districts in England and suggested that “the mysteries of the trade become no mysteries, but are as it were in the air”: He seems to have implied that the dispersion of tacit knowledge is inherent to the industrial districts, as a geographically bounded common good. Krugman (1991) identified local knowledge externalities as one of three reasons for agglomeration of firms; the others being a pooled market of workers, and the availability of specialized inputs and services.

A cluster thus seems like a fertile region for efficient technology diffusion: One firm might acquire or develop new knowledge, and through its position in the intra-cluster network, this new knowledge can diffuse among cluster actors (Giuliani, 2005). Indeed, Baptista (2000; 2001) found evidence for more rapid technology diffusion in geographical areas where the density of sources of relevant knowledge was higher.

The concrete mechanisms through which knowledge is transferred in the domestic environment, can take many forms. Insights into knowledge that resides in other company might be exposed through buyer- or seller relations, or through informal interaction (Saxenian, 1996). All these might be considered elements of the localized external economy. In addition, researchers (e.g. Schmitz, 2000) have highlighted the benefits of deliberate efforts for cooperation and joint actions among cluster participants. De Propris (2002) found evidence for improved innovation activity when local firms joined together in R&D activities. Collaborative activities with elements of knowledge exchanges seem supportive of efficient knowledge diffusion.

Another mechanism for knowledge dissemination is the flow of human capital between industry participants. Knowledge is often embodied in the skills of workers (e.g. Dosi, 1988; Angel, 1991; Lundvall, 2007) and the flow of skilled and talented individuals within a domestic industry provide an efficient way for the sharing of tacit knowledge, experiential knowledge, and best practices (Morosini, 2004). Power and Lundmark (2004) added that besides faster knowledge dissemination, inter-firm labor force mobility would likely lead to new combinations of the knowledge that is embodied in workers, and to informal linkages between firms through social relations. In addition, mobility might facilitate the reallocation of talent and knowledge towards firms with superior innovations (Fallick, Fleischman and Rebitzer, 2006).

Clusters are also conducive for new business formation (Porter, 1998). Knowledge spillover theory of entrepreneurship is concerned with discussing localized knowledge spillovers as an important antecedent to entrepreneurial activity (e.g. Acs et al., 2009): When one incumbent firm invests in new knowledge, it might or might not choose to appropriate the value of this knowledge. If it chooses not to, there is still the chance that individuals with insight into the new knowledge value it differently. The individual might then choose to exploit the value potential of the knowledge spillover by establishing a new firm. The spin-off becomes the mechanism through which the knowledge spillover is commercialized (Acs et al., 2009). Due to the spatial dimension of knowledge spillovers, these new firms are "born local" (Acs and Terjesen, 2007), meaning that they often locate themselves in the same geography.

In addition to commercial ventures, it is important to note that non-commercial actors also play significant roles in the domestic knowledge systems. Institutions providing research and education, whether they are private or public, are vital to the actors in the localized knowledge systems (Saxenian, 1996). Such institutions are often the origin of new knowledge that might spill over to local firms (Audretsch, 1998). Nelson (1993) highlights industrial and government research laboratories as among the core institutions in national systems of technical innovations.

Based on literature investigating mechanisms for knowledge spillovers among localized firms, we propose the following:

Proposition 1b: In an efficient technology diffusion system, there is a presence of:

- *i)* *Local collaborative activities*
- *ii)* *Intra-industry mobility of workers*
- *iii)* *Historic spin-off processes that have resulted in new domestic firms*
- *iv)* *Relevant research institutions*

2.4 The international knowledge networks

Knowledge networks can also be conceived of outside of a cluster or domestic setting. Firms take positions in international knowledge networks that allow them to identify and adopt technology that does not exist in their domestic environments. Compared to literature on localized knowledge networks, we are surprised to find far fewer research contributions investigating the significance of international knowledge networks. Some considerations of international knowledge transfers have been identified in international spillover theory and in international business literature.

The research field of international spillovers investigates the extent to which domestic firms identify and acquire knowledge through international trading channels. Firms that are engaged in sourcing or sales activities internationally might come in contact with sources for new knowledge: Grossman and Helpman (1991, p.238) argue that "the most important benefit to a country from participating in the international economy might be the access that such integration affords to the knowledge base in existence in the world at large". They continue by suggesting several ways by which trade facilitates the exchange of ideas and knowledge: International trade often involves commercial interaction between the trading partners, enabling exchange of tacit knowledge. Imports may embody knowledge that can be understood through inspection. In addition, trading partners might suggest new ways to improve certain company processes.

Coe and Helpman's (1995) important contribution investigated international spillovers through the import channel. Their findings indicated a beneficial effect of foreign R&D on domestic productivity, with the authors arguing that imports allowed for "learning about new technologies and materials, production processes, or organizational methods" (p.860). Open economies benefitted more from foreign R&D than less open economies, because of their higher exposure to foreign knowledge through trade channels. Subsequent articles have largely confirmed the existence of international spillovers through imports (e.g. Coe, Helpman and Hoffmaister, 1997; Acharya and Keller, 2009).

A subfield referred to as learning-by-exporting (LBE) makes the argument that the exporting channel is a way for new knowledge to enter the domestic knowledge system. Silva, Afonso and African (2012, p.35) argue that "firms learn to innovate and to be more efficient as they come into contact with certain informational flows from their buyers, competitors and other sources that are unavailable to non-exporters". Delgado, Farinas and Ruano (2002) suggest an even more significant effect for young exporters.

Also outward foreign direct investment (FDI) has been found to be an efficient way to transfer knowledge to the domestic knowledge system. Van Pottelsberghe de la Potterie and Lichtenberg (2001) were among the first to find supportive evidence of international spillovers through this trade channel. The effect was especially strong when the domestic firm invested in R&D-intensive foreign countries. Branstetter (2006) argued that FDI was an especially effective channel for international technology diffusion, because geographical proximity facilitates and reduces the cost of accessing foreign firms' knowledge assets.

In addition to trade relations, firms increasingly build cooperative relationships with foreign partners in order to sustain and enhance their competitiveness (Lam, 1997). Such collaborations might expose domestic firms to new knowledge, with the effect of transferring knowledge into the domestic knowledge system. In particular, scholars have argued for R&D collaborations as an efficient conduit for knowledge transfers (e.g. Miotti and Sachwald, 2003; Sampson, 2004).

Reviewing theories on international knowledge networks, we propose:

Proposition 2: In an efficient technology diffusion system, there is a presence of:

- *i) Transfer of knowledge through international trading channels*
- *ii) International collaborative activities*

2.5 A model of international technology diffusion

When the concepts of the localized knowledge networks and the international knowledge networks are combined, a coherent model for understanding the diffusion of technology will emerge. The two systems are combined through any commercial or non-commercial actor that holds a position in networks of both a national and international character. This actor acquires new knowledge through its international knowledge channels, and diffuses it domestically through its domestic knowledge networks. See Figure 1 for an illustration.

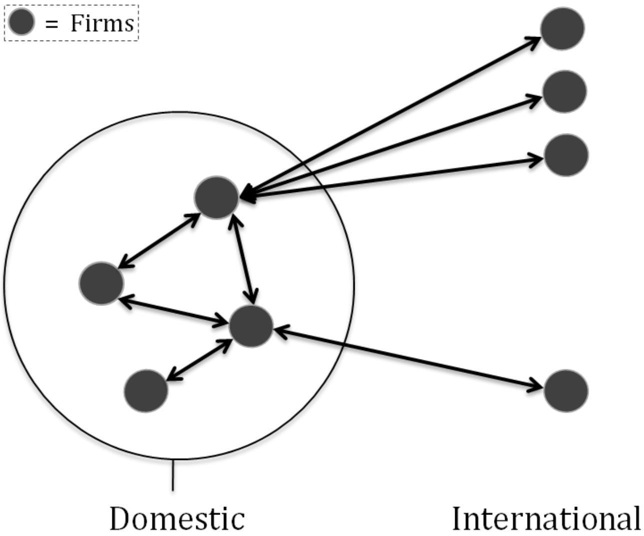

Figure 1: A model of international technology diffusion

Giuliani (2005) refers to the firm that plays the dual role of acquiring new knowledge outside of the cluster, and of transferring knowledge to the firms inside of the cluster, as a *Technological Gatekeeper*. We adopt this expression to describe the firm that is engaged in both domestic and international knowledge channels, and who transfer knowledge in any of these directions: Either from the domestic actors to international actors, or vice versa.

In addition to the technology gatekeeper, the technology diffusion model might be made up of other categories of actors. Giuliani and Bell (2005) identifies the following: A *Local Absorber* is a firm that benefits from absorbing intra-cluster knowledge, while a *Mutual Exchangers* play a more balanced source and absorber role in the cluster environment, at the same time as it might be connected externally. Firms that have established strong linkages with international actors, but whose interaction with domestic firms is limited, are referred to as *External Stars*. Any firms that is poorly linked to both the domestic and international knowledge networks, are *Isolated Firms.*

Giuliani (2005) used the notion of the technological gatekeeper to emphasize the important interplay between intra- and extra-cluster knowledge systems. Bathelt, Malmberg and Maskell (2004, p.3) constructed a similar model, critiquing pure cluster models and arguing for the “need to go beyond the borders of the cluster and build pipelines to bodies of knowledge residing elsewhere – sometimes very far away”. These “pipelines” become a way to overcome shortcomings in the local knowledge system, even though they have to be established through conscious, and often costly, efforts. Gertler and Levitte (2005) investigated the geography of knowledge flows in the

Canadian biotech industry, and revealed a complex net of both local and global linkages. The most innovative firms were connected both locally and internationally.

Consideration should be given to the different actors that take important roles in the technology diffusion system (Giuliani, 2005). We have defined the technology diffusion system as one consisting of firms that are competitive in international markets. In the following we investigate three types of international firms.

One category of such actors is the International New Ventures (INV), with INV being defined as "a business organization that, from inception, seeks to derive significant competitive advantage from the use of resources and the sale of outputs in multiple countries" (Oviatt and McDougall, 1994, p.49). Zahra and George (2002) argue that INVs stand out on three dimensions when compared to other international firms: They have an intense internationalization behavior, with a large part of total revenue incurred abroad. They internationalize fast, meaning that they conduct international activities soon after their inception. They also tend to have a large scope with activities in several markets.

INVs often rely heavily on alliances and networks in order to gain access to critical processes (Mudambi and Zahra, 2007); thus, they interact extensively with other economic actors. This interaction might take place in their home environment (Fernhaber, Gilbert and McDougall, 2008) and with international actors (e.g. Freeman, Edwards and Schroder, 2006). INVs are also found to be more efficient in assimilating new technology than older firms, something Autio, Sapienza and Almeida (2000) refer to as a learning advantage of newness. These characteristics of the INV seem to suggest that it is an efficient agent in the technology diffusion model.

A second category of actors with domestic origins are those following a more step-wise approach to internationalization. These actors can be understood through Johanson and Vahlne's (1977) Uppsala model: Firms are seen as going through gradual internationalization rather than spectacular foreign engagements. The firms often consider organizational scale an important competitive advantage in the international arena, and they believe that experiential knowledge is necessary in order to advance their internationalization (Andersen, 1993).

According to Johanson and Vahlne (2009), a firm's success is dependent on a well-established position in one or more networks, and internationalization is seen as the outcome of a firm's actions to enhance such network positions. It is thus natural to assume that, as soon as the firm has gained international presence, it is still embedded in domestic knowledge networks. Consequentially, firms that internationalize gradually might be efficient technological gatekeepers.

The third group of international firms with presence in the domestic knowledge system is MNC subsidiaries. Multinational corporations (MNCs) might be thought of as firms that have internalized some or all of their international knowledge channels (e.g. Martin and Salomon, 2003). For an MNC, the domestic subsidiaries can be sources of ideas, skills, and knowledge that might benefit the entire company (Bartlett, 1986), and efficient diffusion of such capabilities throughout the organization is often a managerial priority (e.g. Sölvell and Zander, 1995). Indeed, national subsidiaries in different countries have the potential of being creators, adopters, and diffusers of knowledge in the multinational organization (Ghoshal and Bartlett, 1988).

When MNC presence is established through the acquisition of a domestic target, part of the motivation might be to acquire knowledge that resides in the targeted company, and transfer it to other parts of the MNC (Bresman, Birkinshaw and Nobel, 1999). MNCs might also be motivated by the intention to tap into and become part of the domestic knowledge network (e.g. Kuemmerle, 1997).

MNCs work as technological gatekeepers only if they are embedded in domestic knowledge networks (Veugelers and Cassiman, 2004). Birkinshaw and Hood (2000) found that many MNC subsidiaries indeed interact extensively with local actors, especially in leading-edge industry clusters. Researchers within the international spillover tradition have found evidence for beneficial spillover effects for the countries in which MNCs invest (e.g. Branstetter, 2006; Bodman and Le, 2013).

Proposition 3: In an efficient technology diffusion system, there is a presence of actors with positions in both domestic and international knowledge systems.

Figure 2 is an illustration of the propositions 1 through 3.

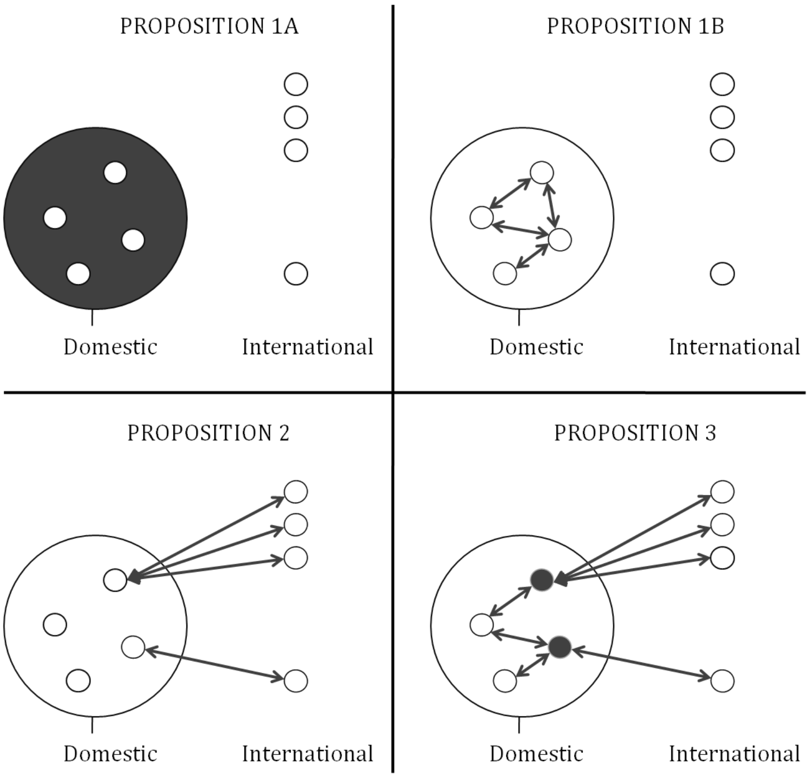

Figure 2: Illustration of proposition 1 trough 3

Lastly, we include a proposition to investigate whether the structures of the diffusion model are static, or whether the model must be understood as a dynamic process where relative importance of knowledge exchange mechanisms change over time. Giuliani and Bell (2005) suggest that the diffusion model could be dynamic, and they envision several different end-stages towards which the knowledge structures might evolve. On the other hand, some of the research traditions that have been included in this theoretical review outline knowledge diffusion models that are static in nature: The researchers review one-period evidence to conclude on aspects of knowledge exchanges (e.g. Audretsch and Feldman, 1996; Audretsch, 1998). Bathelt et al. (2004) construct their model of clusters and global pipelines without suggesting model dynamism.

Proposition 4: In the efficient technology diffusion system, the preferred knowledge networks of domestic actors do not change over time

Part 3: Methodological overview

3.1 Rationale and assumptions for research method

The purpose of this study is to investigate the structures of technology diffusion, and the details of how it happens domestically and internationally. Qualitative research methods stand out as the most appropriate methods, due to the complexity and context-sensitivity of the subject matter. This is also in line with Krugman's (1991) observation about the difficulties in tracing knowledge flows through quantitative measures.

A case study methodology was found to be favored for the investigation. The research questions focus on *how* technology diffusion is happening, and there is no need for controlling behavioral events. The propositions, and their relations to the technology diffusion system, were derived to direct attention to the empirical evidence that should be collected, and a case study seem appropriate to guide this data collection, and to present and analyze the findings. Through triangulation of multiple sources of evidence, a case study can be just as powerful a research method as statistical methods (Yin, 2009). Keller (2004, p.17), reviewing current research on international spillovers, called for more qualitative studies in technology diffusion research, stating that "case studies can offer a rich description of the setting and the major factors that determine international technology diffusion".

Alternatively, a history methodology could have been used if it was decided to limit the focus on current events. A history methodology is, according to Yin (2009), preferable if one is only dealing with the "dead" past. It is believed that the study will be strengthened by the inclusion of current sources of evidence, such as interviews with persons involved in the phenomena studied. A case study research methodology was found preferable, as the intention is to include observations on ongoing diffusion processes, and comment on contemporary aspects.

All of the propositions were based on the definition of an efficient technology diffusion system (see section 2.2), derived from theory, as a domestic country with:

- The presence of a distinctive technology that originated abroad
- The presence of several national actors whose products have integrated this technology as a defining feature
- Competitiveness over time for these national actors in international markets

Consequentially, it is appropriate to use this definition as guidance when screening for appropriate cases. In addition to these three characteristics, a set of criteria was introduced to direct the search further: The technology diffusion system should be encapsulated in a specific industry, so that its narrative is easily conveyed, and the boundaries of the diffusion system are understood more intuitively. This is also believed to ease data collection. In addition, it was decided that the industry should be mature, but not too old, so that documents, archival data and interviews with key personnel, effectively covering the entire history of the industry, were easily accessible. A Norwegian industry was preferable, given the Norwegian locality of the investigators, and their proficiency in the Norwegian language. A short summary of the industries that were screened can be found in Appendix A, with the full descriptions saved in the case study database.

The Norwegian microelectronics industry turned out to be the single most applicable case, fulfilling all the predetermined criteria. The industry is based on a relatively young technology, related to transistors and integrated circuits, which had its conception in the US in the 1950s. Activities were initiated in Norway in the 1960s, and currently several Norwegian companies, with successful operations in international markets, are basing their primary business activities on microelectronics expertise. There had been no previous attempts at mapping the industry and its market and technology trajectories, and the contribution of depicting the industry evolvement were thought to arouse some interest. Such interest was also thought to ease the access to first-hand sources. In the end, considering the alternatives, it was believed that a case based on this industry would provide a good basis for discussing the propositions, and lend insight to the focal research areas.

As an additional trait, it was decided that a single-case study, as opposed to a multiple-case study, was most appropriate. For one thing, a single-case design allows for more depth in the data collection and subsequent analysis. In addition, the case of choice can be considered critical: As according to Yin (2009) it is highly consistent with the circumstances under which the propositions are believed to be true, as specified in the definition of the efficient technological diffusion system. In particular, the field of microelectronics stands out as a "distinctive technology"; it belongs to a well-defined technological domain, meaning that knowledge diffusion trajectories will be fairly recognizable. The investigators are aware of the strengths of a multiple-case design, in particular its compelling connection to external validity through replication logics, but the pursuit for depth took precedence. Indeed, if this study was to be followed up on, one method could be to investigate prevalence of proposed aspects in other industries. Then one could comment on the findings of that study to validate the extent to which the results of this study are generalizable.

The methodology employed follows the recommendations of Yin (2009) for case study research. The rest of this chapter will discuss the choices made throughout the study, from design, through preparation and collection of evidence, to the analysis and presentation of this data.

3.2 Design and choice strategy for the case study

A large number of Norwegian businesses are affiliated with microelectronics in their daily operations. Some organizations have in-depth knowledge in the implementation and use of such technology; others may develop it for internal or external use. It was a need to specify the type of firms that could be considered part of the industry. We used the following definition as an inclusion criterion: A firm was to be considered part of the Norwegian microelectronics industry if design of semiconductor based electronic chips is considered to be the one, or one of a few, primary business activities of the firm. This business activity had to take place in Norway.

Based on this definition, the number of relevant companies was still high, and a trade-off had to be made about whether to attempt to span most of these companies in the case, or to choose a handful for a more in-depth study. The latter approach was deemed preferable, due to aspects that supported a higher quality case study design: A handful of organizations would be easier to handle for the two inexperienced investigators. It was also thought that the intangible nature of knowledge spillovers and technology flows demanded some depth in the observations, at the same time as an in-depth study would enable use of a larger body of source material, supporting construct validity.

The Norwegian microelectronics industry can be subdivided, as seen in Table 1, into roughly three groupings, based on the firms' products:

Table 1: A subdivision of the Norwegian microelectronics industry

Products, and firm categories	*Examples, and approximate number of actors*
Sensors, microelectromechanical systems (MEMS)	Novelda, Ideas, OmniVision Technologies, Idex, Sensonor (20 +)
Large design houses	Nordic Semiconductor, Atmel Norway, Texas Instruments Norway, ARM Norway, Energy Micro (5)
Companies having microelectronics as an internal competence, often related to own product chain	Hittite Microwave Norway, GE Vingmed Ultrasound, Kongsberg Norspace (20+)

The second group of firms stands out from the others in that their value proposition to customers are offered through internally developed chip designs. Contrary to firms in the other two groups, this knowledge is the primary business activity of the firms, making it easier to trace the history and sources of the firms' technological advancements. These five firms also have a larger international footprint than the firms in the other groups, and have been highly competitive for several years, as evidenced by exports ratios and revenue growth. The firms are heavier in the design phase of semiconductor business activities, and several of the firms in both the first and third category are former or current customers.

Based on these arguments, it was decided to focus on the industry comprising of the firms in the second category. Each of the industry firms, to be regarded as the commercial actors of the theoretical models, is considered a unit of analysis. On the onset of the case study, five firms had been identified; those that are found in Table 1.

However, this list was not permanent, and more firms would be included as the study progressed. In addition, as derived in the theoretical overview, research institutions might play important roles in the technology diffusion system. As such, research institutions will also be considered units of analysis in the case study. The final list of all units of analysis is found in Appendix B, together with general information about the focal companies.

Contextual actors are all the actors that have or have had influence on the microelectronics industry. The case will not investigate these firms as units of analysis, but will indeed comment on them if they happen to become relevant to the focal actors. Contextual actors might include education institutions, customer companies, supplier companies and governmental actors. In addition, firms from the other two categories of microelectronics firms might be of interest, if they are made relevant through the focal actors' vertical or horizontal linkages.

In order to secure construct validity, it is necessary to identify the operational measures that are most appropriate for the concepts being studied (Yin, 2009). This thesis is concerned with economic actors' domestic and international knowledge networks, and how these networks transfer knowledge that might be employed for commercial value: The use of this acquired knowledge becomes important for international competitiveness. Based on this line of reasoning, it was decided that the case study would be occupied with the following:

- First, it is necessary to understand the *key products* and *solutions* that commercial actors are offering, and how these offerings have evolved historically. Indeed, it is through distinct product offerings that the actors build competitive advantages.
- Next, the case study will identify the *key processes* that the commercial actors went through in order to initiate and develop their competitive product offerings. Such processes could include strategic decision-making, product development and firm establishments.
- Ultimately, the case will seek to identify the *knowledge networks* and the *transfer mechanisms* that have been instrumental to these processes. When possible, knowledge antecedents will be traced back to the point at which it first entered the domestic knowledge system.

The case study will consider the full history of the microelectronics industry. An historical approach is also necessary in order to test Proposition 4), regarding the static nature of the diffusion model.

Formally, the study will follow an embedded single-case design with multiple units of analysis. Figure 3 is meant to illustrate the decisions made in the design phase of the case study.

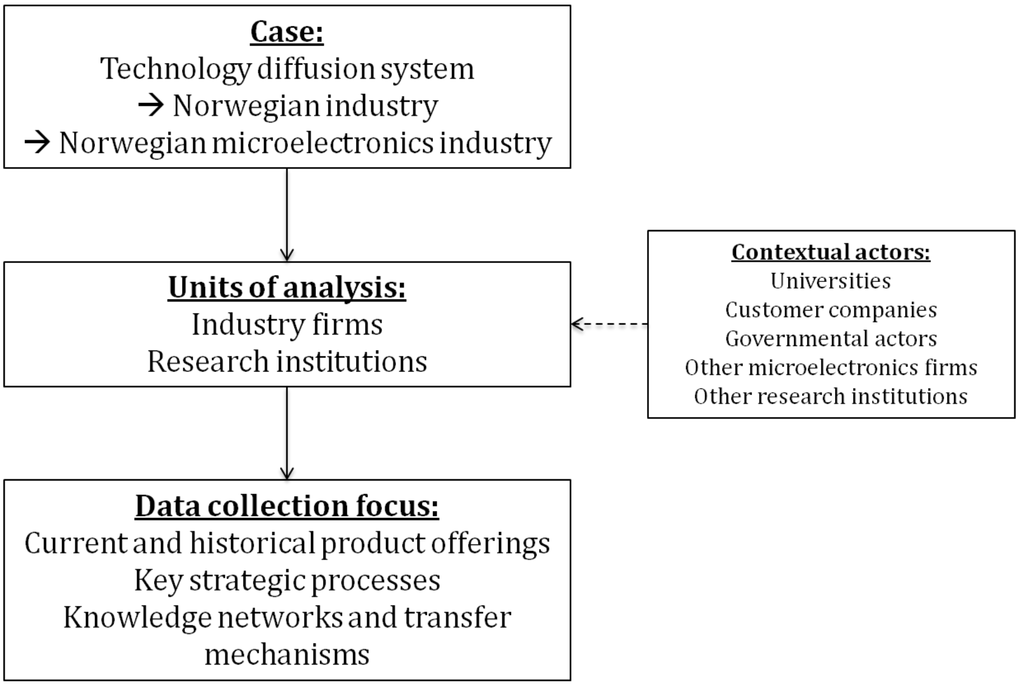

Figure 3: Decisions made in design phase

3.3 Preparation and collection of case study evidence

In the preparation phase of the case study, it was identified a need to evaluate the two investigators' skills and experience within three distinctive domains: Theoretical knowledge of technology diffusion, understanding of technological aspects in microelectronics, and experience in conducting a case study research. If the required skills were found to be lacking, concrete actions had to be taken.

First, both investigators had extensive knowledge about large parts of the theoretical foundation prior to initiating the case study. This knowledge stems mainly from their joint paper, Aglen and Graff (2012); an exploratory study investigating how International New Ventures (INVs) relate to economic development. During the study, an extensive literature review was conducted in the areas of international entrepreneurship, economic growth models, international spillover theory, and cluster theory. This case study would have a somewhat wider focus, with models that incorporate other commercial actors than just INVs, and so several new theoretical concepts were thoroughly reviewed. These included theory on multinational corporations and theory on international strategic alliances.

Second, the investigators had limited prior knowledge about the Norwegian microelectronics industry, and their technological education hadn't focused on microelectronics in particular. In order to be able to trace strategic choices, product development and other aspects of the industry, some basic topical knowledge would be necessary. An effort was made to read up on the topic of microelectronics through the Internet and a number of textbooks, including Liu (2006) and Banerjee and Streetman (2009). In addition, an introductory session with an electronics professor at NTNU was conducted. Both of the investigators had had three years with technology courses at university level, with one of them specializing in high voltage electronics systems, so closing the knowledge gap seemed manageable.

With regards to the third aspect, Yin (2009, p.68) states that "a well-trained and experienced investigator is needed to conduct a high-quality case study because of the continuous interaction between the theoretical issues being studied and the data being collected". Neither of the investigators had any prior experience in conducting a case study, and saw it necessary to prepare extensively for the interviews and collection of evidence. Yin (2009) lists five skills typical for a high-quality investigator: The investigator should be able to ask good questions, be good listeners, be adaptive and flexible, have a firm grasp of the issues being studied, and be unbiased by preconceived notions. This skill set was used as guidance for each of the investigators throughout the case study.

A case study protocol was developed early in the process, and was used as guidance through the general collection of data. The initial protocol can be found in Appendix C. A variety of sources were used, for the purpose of securing construct validity. Table 2 summarizes the different categories of sources. The most important of these will be discussed at greater length.

Table 2: Sources of evidence collected throughout the case study

Sources of evidence	*Type of information*	*Retrieved from*
Documentation	News clippings	Retriever, newspapers' websites
	Employment statistics	LinkedIn
	Annual Reports	Company websites
	Company information	Company websites
	Industry technical information	Books, reports
	Other general historical information	Web, key insiders of companies
Archival records	Archival company data	Proff Forvalt
	Official company announcements	Brønnøysundregistrene
Interviews	In-depth interviews	Key insiders of companies
	Focused interviews	Key insiders of companies

Historical news clippings were thought to be a good, unbiased way for building the foundation for our understanding of the companies' histories. In order to retrieve and assemble the clippings, the media search tool Retriever, the largest vendor of media monitoring and evaluation tools in the Nordic countries (Retriever AB, 2013), was used. The searches were restricted to Norwegian press only, meaning that the search tool would scan the historical archives of 154 unique printed newspapers, and 1 171 electronically based sources.

Searches were conducted for each the firms considered units of analysis. The numbers of retrieved articles from each of the searches are listed in Table 3. After the searches were conducted, a file comprising all the news clippings were saved into a PDF-file, sorted in reverse chronological order, from oldest to newest. A manual screening of each of the news clippings was done, and a brief summary for each of the companies' historical events that were deemed relevant was written. The summaries were collected in a separate file, and used extensively when writing the historical account of the industry.

Table 3: Overview of searches conducted in Retriever

Company (search words)	*Number of articles retrieved*	*Comments*
Nordic Semiconductor Nordic VLSI	1 950	[Retrieved: 20.02.2013] The major news sources for stock exchange updates, in addition to NTBtekst, were removed due to irrelevance, and are therefore not included
Atmel	578	[Retrieved: 18.02.2013]
Falanx ARM Norway	179	[Retrieved: 21.02.2013]
Chipcon Texas Instruments	694	[Retrieved: 20.02.2013]
Energy Micro	121	[Retrieved: 25.02.2013]
Chipidea Arctic Silicon Devices Hittite	33	[Retrieved: 26.02.2013]
FXI Technologies	31	[Retrieved: 14.03.2013]
Gran Jansen Blue Chip Micrel	108	[Retrieved: 19.03.2013] Articles using the business concept "bluechip" are not included

A second type of documentation was withdrawn from LinkedIn, the world's largest professional network site (LinkedIn Corporation, 2013). The purpose was to document the historical flow of labor between the different industry participants. The data was withdrawn manually on March 1st, 2013, by looking up all current employees in the different firms, and combining the results with searches for previous employers and places of education. This method has some shortcomings. For one, not all firm employees own LinkedIn accounts. 456 accounts were identified, whereas the focal firms employed in total 610 in the same period. Second, information may be false as there are no entities controlling what a person registers, or chooses not to register, on their professional profiles. However, LinkedIn has some regulations aimed at reducing such potential errors, and for a large sample some of the errors will be leveled out. In the end, LinkedIn, with more than 225 million members, of which 720 000 users are registered with Norway as their place of residence (LinkedIn Corporation, 2013), is believed to be the best publicly accessible place for retrieving such figures.

The other types of documentation and archival records were retrieved on a continual basis as the need for them arose throughout the study. Such needs arose as different aspects in need of verification were identified through other sources, or when other sources could illustrate aspects of the case in a different light. These sources of evidence are all publicly available.

Financial data over time could have been useful in illustrating the growth and development of the focal firms. Unfortunately, such data proved difficult to retrieve. Either they were not publicly available, or they were highly distorted due to the companies' reporting routines. Today, three of the focal companies are subsidiaries, and their parent companies report financial figures to Norwegian authorities that cover the subsidiaries' labor costs and operational expenses, but not necessarily revenues that stem from the domestic companies' design activities. The parent companies do not break down figures on the level of country subsidiaries in their annual reports; indeed, due to their nature as design centers, it is often difficult to pinpoint value add of the Norwegian offices' activities. In addition to the subsidiaries, Nordic Semiconductor, listed on the Oslo Stock Exchange, has changed their reporting structures in recent years, so time trends are difficult to illustrate. Instead of referring to financial data, efforts have been devoted to portraying the success of the firms' product offerings through testimonials, and by describing the market response. Sometimes year-on-year growth percentages are used based on figures reported in historic news clippings.

Interviews with industry and company insiders were, in addition to the news clippings, the most important sources of evidence for the study as a whole. The news clippings were reviewed first, and based on the findings here a first impression of the industry was built. The interviews would follow, with two main purposes: To verify the events as they were reported in the media, and to clarify areas in which information was lacking. Other documentary and archival records were used continually through the whole period to support the data collection.

In total, ten interviews were conducted, of which six were in-depth interviews, held at location in Oslo or Trondheim, or by Skype, in the course of two weeks in the beginning of April 2013. Each of the interviews was with a person that had been identified as a key insider for one, and in some cases two, of the focal companies. Two types of informants were targeted: Insiders in management positions, with insights into the companies' strategic decision-making processes, and company founders. The list of informants was meant to cover the current and historic situation of the industry firms.

For each of the in-depth interviews the investigators prepared a list of questions that was meant as guidelines to ensure that the conversation touched upon a few predetermined topics. During the interview, the investigators strove to let the informants provide the insight they deemed most important. The informants were encouraged to express their own reflections and opinions about the industry as a whole, and their thoughts about the development and growth of industry actors. When informants were less open and talkative, it became necessary to ask more detailed questions, to make sure that the relevant topics were covered. All of the in-depth interviews lasted between 75 and 180 minutes.

In order to validate some of the choices made in the case study, all interviewees were asked the following open questions: To validate case scope, the interviewees were asked to name the other companies they considered to be part of the same domestic industry. To validate the choice of key informants, it was asked what other individuals it could be relevant to talk to. The interviewees' answers were supportive of the choices made.

The last four interviews were held in early May 2013, either by Skype or by phone. The broader description of the industry, along with the historical accounts of the major companies, had been covered through the six in-depth interviews, and so the last interviews were more focused on particular events. Some aspects were in need of verification, while other aspects had to be elaborated on due to a lack of detail in other source material. The interviews were still conducted in an open manner, allowing for flexibility in the topics covered. All of the focused interviews were shorter than 60 minutes.

The case study protocol was written before any of the data collection had started, so it only contains the general topics that the interview process was meant to cover. The specific questions prepared for each interview is too extensive to be included, but they have been retained in the case study database.

In a case study, the protection of human subjects is important (Yin, 2009). Full identification of interviewees was employed, though, in order to lend credibility to the statements used. Several interview objects were key participants in processes that shaped the industry, and their first-hand accounts were highly insightful. Few topics were identified where anonymity might have motivated the interviewees to tell different stories. Also, omitting names when quoting interviewees wouldn't always guarantee anonymity, because the information that the quotes conveyed was often traceable to the particular sources. Thus, at the start of every interview, an oral agreement was made about the use of names and citations in the case narrative. A quotation check was offered as well, and those who affirmed (two informants) were sent a collection of their quotes for review. The interviewees were also informed about the recording of the interview session. The final report was emailed to all of the informants.

All interviews were conducted in Norwegian. Since the language of the study is in English, it became necessary to translate the quotes that were chosen. The investigators have done so after best efforts, while trying to preserve the colloquial nature of the interviewees' responses. The full list of quotes in their original language is retained in the case study database. Sometimes quotes have been retrieved from news clippings or websites, and then the source will be referred to. If the investigators have translated these quotes, a notice has been included.

Table 4 presents each of the interviewees, in addition to the date of the respective interviews and the major topics covered.

Table 4: Presentation of the interviewees

Name and date	*Company and position*	*Major topics covered in the interview*
Jo Uthus [02.04.2013]	Atmel, Director of Applications	In-depth interview topics Historical review of Atmel
Svein-Egil Nielsen [03.04.2013]	Nordic Semiconductor, Director of Emerging Technologies and Strategic Partnerships	In-depth interview topics Historical review of Nordic, targeted at partnerships and standardization work
Borgar Ljosland [04.04.2013]	FXI Technologies, co-founder and CEO Falanx Microsystems, co-founder and former CEO	In-depth interview topics Historical review of Falanx Microsystems and FXI Technologies
Geir Førre [08.04.2013]	Energy Micro, co-founder and CEO Chipcon, co-founder and former CEO SI, former researcher	In-depth interview topics Historical review of the whole industry Historical review of Chipcon and Energy Micro
Karl Torvmark [09.04.2013]	Texas Instruments Norway, Strategic Marketing	In-depth interview topics Historical review of Chipcon, targeted at standard components and standardization work
Trond Sæther [12.04.2013]	Nordic Semiconductor, co-founder and director of IPR, ELAB, former researcher	In-depth interview topics Historical review of the whole industry Historical review of Nordic
Øystein Moldsvor [13.05.2013]	Hittite Microwave Norway, co-founder and CTO Nordic, former R&D director Data Converters	Historical review of data converter activity at NTNU, ELAB, Nordic and Hittite Microwave Norway
Frank Berntsen [14.05.2013]	Nordic Semiconductor, co-founder and chief scientist ELAB, former researcher	Historical review of P-RISC / µRISC

Oddvar Aaserud [15.05.2013]	Nordic Semiconductor, co-founder and former CEO ELAB, former researcher	Historical review of the industry, targeted at the first decades
Petter Gran-Jansen [21.05.2013]	Gran-Jansen, founder and former CEO	Historical review of Gran-Jansen

The use of triangulation of the different sources of evidence was pursued throughout the case study. For the most part, the combination of at least two types of sources has been used to validate particular events: At least one source of documentation or archival record, in combination with the testimony of at least one interviewee. Quotes were used in those situations where statements in interviews could not be backed by alternative sources, but when the descriptions were considered insightful for the case. Examples include statements of personal thoughts or reasoning about the course of events. Quotes were also used in situations where the personal statements lend credibility to the narrative, often due to the individual's central position in the situation depicted.

The case study database contains all the information collected by the investigators throughout the case study period. This includes all the literature used in the theory development part of the study, with the exception of books and reports borrowed from libraries (but these are traceable from the list of references). All of the clippings that resulted from the newspaper searches can be retrieved, in addition to short description of the most noteworthy events for each of the companies. Only those extractions from archival records that were used in tables in the report are saved in the database. The records they were retrieved from are considered stable: They are rarely subject to any modification that could undermine the reliability of their use in the report.

Transcriptions of the in-depth interviews, and audio recordings of all the interviews, in combination with the case study protocol and the specific questions prepared for each interview, are also found in the database. In effect, the investigators have ensured that an inspection of the case study database should allow subsequent researchers to trace the historical and current accounts that are depicted in the case study report; through the case study protocol, all the way back to the case study questions.

Figure 4 shows the revised timetable of the case study.

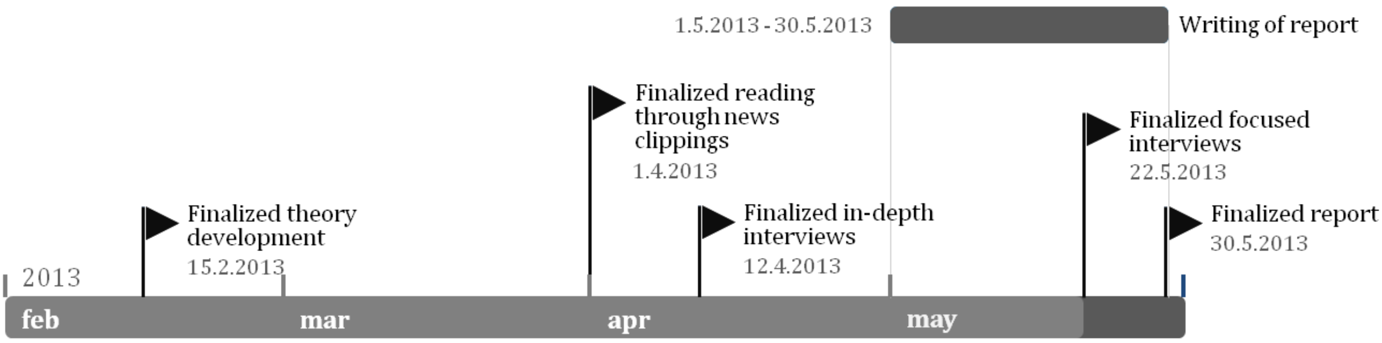

Figure 4: Revised timetable of the case study process

3.4 Analysis and presentation of case study evidence

The format of this case is what Yin (2009) referred to as a classic single-case study. One narrative, the one of the Norwegian microelectronics industry, is presented, supplemented by illustrative table and charts displaying archival records. The structure of the full report follows a linear-analytic structure (Yin, 2009), which is a standard approach in many research reports: First, a literature review with derived propositions, then a methodology chapter, followed by a chapter where the case depiction is found, and where the collected data is presented. The report ends with a chapter that discusses the implications of the findings.

The analysis of the case will follow a patter-matching logic, where an empirically based pattern is compared with a predicted one (Yin, 2009). The propositions were derived from theory, and describe characteristics of firms, their networks and domestic conditions that should be identified in an efficient technology diffusion system. If such characteristics are observed, the propositions are supported. As a cohesive diffusion model, the firms' dependence on international and domestic knowledge networks will be discussed. Proposition 4) suggests that the model is static, and in order to test its validity, the rival explanation will be used as pattern: The model cannot be static if the prevalence of characteristics as they are proposed in Proposition 1 through 3 are not consistent through all times in the chronological depiction.

The investigators are aware of the fact that some of the propositions lack precise measures about the characteristics that are to be observed. Indeed, this allow for some interpretive discretion on the investigators' part, as Yin (2009) warned. It was often the case that the reviewed literature also lacked precise measures about the theoretical concepts they described. Such a lack of precision has, for instance, been part of the critique of cluster theory (e.g. Bahlmann and Huysman, 2008; Glăvan, 2008). The investigators followed Yin's (2009) suggestion about avoiding the postulation of subtle patterns, and focus instead on patterns that allow for gross matches or mismatches.

The targeted audience of this case study is twofold. First, there is the academic environment, most notably researchers within the area of international business and cluster theory. It is assumed that, to them, the explanatory power of the case, in relation to the derived propositions, is of most importance. One presentation format befitting of this group could be to give a brief description of the major events of the industry history first, followed by a chapter where data in relation to each of the individual propositions were presented and evaluated.

Second, there is the audience that might be more interested in the descriptive part of the study. It is expected to be a strong presence of insiders in the Norwegian microelectronics industry in this group, due to their access to the report through copies sent to the interviewees. In addition, because of the industry's international success, and the case's discussion of industrial aspects, there might be interest from actors across other industries, education environments and industrial policy makers. To this group of readers, it is believed that a thorough historical overview is key, in order to provide the reader with insight into the full story of the industry, from its inception to the current situation.

The chosen format of a report should be based on the preferences of the targeted audience of the report (Yin, 2009), and after a review of the interests of the two groups depicted above, it is believed that an extensive presentation of the case and the data, told in chronological order, is appropriate. Emphasize will be put on those situations and events that shed light on aspects related to the propositions, with a discussion chapter to tie together the key insights. The optimal solution might have been to write two separate reports, customized for each of the audience groups, but the work that would go into such a writing process is considered out of scope for this thesis.

Part 4: The Norwegian microelectronics industry

This section is an extensive depiction of the Norwegian microelectronics industry, based on the data collected during the case study phase. The data is presented in a historical chronological order, starting with the inception of microelectronic technology in USA, and ending with the current situation of the Norwegian microelectronics industry. Encyclopedias listing all the different entities and people that are part of the story are found in Appendix D and Appendix E respectively.

4.1 The birth of a technology, and the rise of the semiconductor industry

Electronics is the science dealing with systems involving flow of electrons, a science that has enabled a range of new products during the last decades, including TVs, radios and computers. One of the overarching trends in electronics during the last half a century has been the quest for making smaller and more integrated components, a trend resulting in a separate branch of electronics; microelectronics.

The most central component in most electronic units in the first half of the 20th century was the vacuum tube, which was used for switching and amplifying signals. The first TVs and radios were produced using this technology, but the limitations of the vacuum tubes didn't allow them long service life, and they were cumbersome and large in size.

In 1956 three American scientists were awarded the Nobel Prize in Physics for the discovery of the transistor, a semiconductor-based electronic component covering the same need as the vacuum tube, but much smaller and in principle everlasting. The transistor was soon to hold the position as the most central component in most electronic circuits, and, together with the emergence of semiconductor purification, laid the foundation for a growing semiconductor industry.

Shockley Semiconductor Laboratory (SSL), the first company to develop silicon semiconductor devices, was established in an area south of San Francisco in 1956. The founder of SSL, William Shockley, was one of the three scientists behind the discovery of the transistor, but he never fully succeeded as an entrepreneur, and his eight employees, often referred to as the traitorous eight, ended up leaving the company in order to start a number of other semiconductor companies. SLL and these start-ups formed the nucleus of what later became known as Silicon Valley.

The technologies developed in Silicon Valley, as well as by companies situated other places in the US, were soon to spread abroad. Companies were early at licensing technology to factories across the Pacific, and many US-based technology firms built their own factories abroad. Today, the semiconductor industry represents the basis level of value creation in the vast majority of electronic products sold in consumer markets all over the world, from cars to refrigerators, to cell phones, and more. Today's ubiquitous microelectronic components are a result of years of competition and rivalry between players across the world continuously innovating and pushing the limits of current application areas for microelectronic devices.

If more than one electronic circuit is integrated into one single chip we get what is called an integrated circuit (IC). An integrated circuit is built up of numerous logical components, together being able to perform a predesigned function. While the first integrated circuit consisted of a few transistors, today's technology can fit billions of transistors into chips the size of fingernails. To put the development in perspective; the world's first electronic digital computers, first seeing the light of day in the 1930s and 1940s, were the size of small buildings, but could only perform calculations applicable for today's pocket calculators. In 1965, Gordon E. Moore, one of the first employees in SSL and later co-founder of Intel, characterized the development of the semiconductor industry as exponential. He had observed a steady technological improvement leading to a doubling of the density of transistors every eighteen months on new integrated circuits in the market. This observation, referred to as Moore's law, has later been used as a prediction, or roadmap, for the trajectory of the semiconductor market, with actors assuming a continuous fulfillment of the law.

Producing a chip is highly complex, and demands specialized knowledge throughout the different parts of the value chain. Starting with the design stage, the idea of the chip is transformed to detailed chip design by the use of digital or analog designing tools. The design of a chip has to follow certain rules readable for the machinery at the semiconductor fabrication plant, often called a fab. The first semiconductor firms established in the 1950s and 1960s in Silicon Valley and elsewhere were controlling the entire value chain in-house. Today this business model is only maintained in some of the largest firms, referred to as integrated device manufacturers (IDMs).

The modularization of the value chain happened mainly because of an exponential cost level for operating fabs, making full utilization of the fabs extremely important in order to stay profitable. Business models with firms being specialized in either design or manufacturing, so called fabless companies and pure-play semiconductor foundries respectively, are dominating the industry today. This has drastically lowered the barriers for new start-ups making the semiconductor industry truly globalized.

Microelectronic chips of today may be split into three main categories: First, digital components such as microprocessors and microcontrollers, make use of information in discrete numbers to conduct calculations. Analog components, the second category, are often used to filter and amplify electrical signals. The third category is mixed-signal components, which make use of both digital and analog technology. Examples include sensor systems where an analog signal such as sound is transformed to a digital signal in a mixed-signal chip.

4.2 The first traces of a Norwegian semiconductor industry (1962–1983)

The roots of the microelectronics design industry in Norway can be traced back to the pioneering work of Olaf Stavik. He had come in contact with the new technology in North America, first through work at the University of Pennsylvania, US, then through five years researching transistors for Northern Electrics in Canada. Deeply impressed by the seemingly never-ending line of applications made possible by these transistors, he returned to Norway with great enthusiasm, and took the initiative to start a research community within integrated circuits at the Central Institute for Industrial Research (SI) in Oslo. In 1962 he and his team managed to build one of the first transistors in Europe, and followed up by constructing Norway's first integrated circuit a few months later. At the time, microelectronics was a discipline most people in the electronic industry in Norway were unfamiliar with. The great call for awareness came at a national industry event in 1963, where Stavik presented his predictions about the immense potential of microprocessors, or "the computer that fits into one chip".

SI continued conducting research in microelectronics through a dedicated electronics department. Among the work of greatest significance was their contribution in micro-electro-mechanical systems (MEMS), laying the foundation for a sensor-technology cluster that would be located in and around the municipality of Horten, Norway. Stavik himself participated in the establishment and management of a number of firms in this area from the late 1960s onwards.

SI had its origins in the University of Oslo (UiO), and was established in 1949 as a national center for applied technical research. The intention was to improve the cooperation between the Norwegian industry and the university. Another research institution, The Department for Scientific and Industrial Research (SINTEF) was established the year after, in 1950, based on the same idea as SI but with a partner in another educational institution, the Norwegian Institute of Technology (NTH) in Trondheim. SINTEF's electronics group, ELAB, was founded in 1961,

Two ELAB researchers, Oddvar Aaserud and Kjell Arne Ingebrigtsen, started discussing the prospects of integrated circuit design activities in the late 1970s. These talks resulted in an application for targeted research funds from the Norwegian Research Council, and in 1978, upon acceptance, ELAB initiated their first research activities. At this point, a paradigm shift was imminent in the semiconductor industry, through the introduction of VLSI design methods that allowed for a decoupling of integrated circuit design from production. The shift has been referred to as the Mead & Conway revolution, named after two researchers, Carver Mead and Lynn Conway, whose pioneering book, *Introduction to VLSI System Design*, became the definitive handbook to the VLSI method. The book had inspired Aaserud and Ingebrigtsen, and the method it outlined provided the foundation for ELAB's microelectronics operations. Oddvar Aaserud describes the design revolution:

> There was a change in the way of thinking. The processes had been very secretive and inaccessible, and now they became open, and more alike, and easier to understand. (...) This meant that one could make a distinction between being a designer, and owning the process itself. This was the great divide that happened in the late 1970s. It was basically this that we saw an opportunity to exploit. We had a fairly modest process-technology industry in Norway, but we saw a need for being able to exploit the technology.

To their new department, ELAB recruited researchers from applied sciences, including circuit design and computer-aided design (CAD). Such expertise became crucial in developing VLSI capabilities. In addition, the department would build strong capabilities within the area of simulation and testing. Einar Aas, an ELAB researcher since 1972, had frequented the US to build competencies within microelectronics, and during a stay in Texas, he learned state-of-the art simulation techniques that he brought back to Norway. Much thanks to Aas' work, ELAB enjoyed world-class abilities in predicting the logic behavior of ICs before production, significantly reducing manufacturing risk. The expertise was cultivated further, and came to be recognized also among foreign actors, who occasionally sought advice from the Norwegian researchers.

A third research institution, The Norwegian Defense Research Establishment (FFI), was also established in the postwar period, but they had focused on defense related science. In particular, resources were dedicated to research on radio technology and computer science. In a similar fashion as one had seen in the American defense industry, research on transistors became prominent in the beginning of the 1970s. Two researchers in particular, Yngvar Lundh and Oddvar Søråsen, were central to FFI's microelectronics activities, and would also be contributors to ELAB's initiation of design operations.

In 1978 the three environments at FFI, SI and ELAB identified a common need for new microelectronics equipment. They conducted a joint negotiation for the procurement of state-of-the-art design system tools, and were ultimately offered a discount due to the size of such a contract. This laid the foundation for world-class design research within microelectronics well into the 1980s.

The primary educational institution within microelectronics in this period was NTH, the university with responsibility for all higher technology education in Norway. ELAB was located at the NTH campus, and cooperated closely with the electronics department with the effect of fostering a dynamic research and learning environment. The electronics department became pioneering in offering courses with microelectronics content. Trond Sæther, a person who would be central in multiple Norwegian microelectronic start-ups, recalls the appeal of ELAB as an NTH-student in the early 1980s:

> As a student, I found the microelectronics group at ELAB incredibly exciting. They were working with IC design, or VLSI design, in Norway, and that was as close to science fiction as it could possibly get at the time. Many of us students were pulled as magnets towards the topic, because it seemed so cool and exciting. (…) This was stuff that I had read about in foreign electronics magazines, and heard about from the United States and things like that. And when we then came to NTH, and learned that these activities were

going on at the floor right above our study room, it became incredibly motivating - very exciting.

4.3 Nordic VLSI, and knowledge transfer from research institutions (1983–1994)

From the beginning in 1978, the ELAB microelectronics group was concerned with exploring the commercial potential of their activities. Early on they made a thorough assessment of expected design costs, and found that costs would be much lower than anyone had anticipated, even for low volumes of customized chips. These results were published in the Norwegian electronics periodical, *Elektronikk*, and induced large industrial interest in the electronic circuits that ELAB could provide. In the beginning of the 1980s, the microelectronics group was busy with numerous industry projects.

In 1982, Åsmund Gjeitnes, director at ELAB, encouraged Oddvar Aaserud, director of the microelectronics group, to establish a commercial entity from which they could continue their industrial assignments. The assignments had put pressure on ELAB's resources, both with regards to equipment and to human capital. Norwegian industrial actors, including Stentofon, an intercom systems provider, and Tandberg Data, an information storage provider, also encouraged such a start-up initiative, having anticipated an increased industrial need for customized integrated circuits.

In effect, the first prominent industry participant, Nordic VLSI (later Nordic Semiconductor; referred to as Nordic throughout the thesis) was founded in 1983. Oddvar Aaserud was to be the company's first CEO, and brought with him three other ELAB researchers as co-founders: Jan Meyer had been part of introducing microelectronics as a research field at ELAB, and represented the strong technological experience of the start-up team. Trond Sæther, 25 years old at the time, and Frank Berntsen, 26 years old, were recent electronics graduates that had impressed the more experienced researchers with strong technical abilities. Trond Sæther comments on his and Frank Berntsen's ability to contribute in the start-up team:

> They had the two of us, the rookies, who were still wet behind the ears. But we had covered a new microelectronics education, which, at that time, I perceived to be contemporary, and modern. It was a strong academic environment at the university and ELAB, which offered students a very good, advanced, learning environment that ensured that one came up to speed quite quickly.

Sæther remembers the older team-members as generous in the start-up process, and it was established a flat team structure. While the "rookies" were concentrating on the technology and design aspects of customer projects, the more experienced members of the team also handled administrative and strategic issues, ensuring financial solidity and doing quality checks. Aaserud recalls how much "fun" they had had in the start-up process, with activity both day and night.

The young firm got to be located in Innherredsveien in Trondheim, close to the expertise at ELAB and the recruitment source of NTH. The offices were taken over from Stentofon, who had used them during an attempt to build in-house microelectronics expertise. The attempt was unsuccessful, providing Nordic with an opportunity to acquire state-of-the-arts amenities, including appropriate design systems and simulation ready computers.

The goodwill and involvement of local actors such as Stentofon was instrumental in the early days of Nordic. Industry heavyweights Norsk Data and Autronica provided capital, acquiring significant owner shares; the same did Forenede Forsikring, a national insurance company. Tandberg Data awarded Nordic with a design project that could keep the start-up team occupied and secure cash flow for the first few months.

Nordic was the first company in Norway to offer corporations custom-made chips, so-called Application-Specific Integrated Circuits (ASICs), for industrial purposes. A company would approach Nordic, asking for assistance in developing components that required some kind of microelectronics. Nordic assembled a team that worked on solutions through computer design programs. The finalized products were manufactured by one of several chip producers that Nordic had interactions with, and who did production on a project basis. Most of the producers were located in Europe.

Several researchers would leave ELAB for Nordic during the first few years, and expertise that resided in these individuals left with them. The result was that the ELAB environment at SINTEF, in the aftermath of the Nordic spinoff, never quite regained the high level of microelectronics expertise that it had built since the late 1970s, even though they were awarded research grants to rebuild their organization. Trond Sæther comments on this diminishing role of ELAB:

> In the beginning, I actually think that we had - we had the impression that they were afraid to rebuild their operations (after we left) for fear of doing harm to us – which they would compete against us and stuff. I think those fears were a bit groundless (…). I think that in the end it might even have hurt everyone, because it affected the availability of expertise. Because everyone would have endured and benefited from a strong microelectronics environment at SINTEF. Because they were supposed to be two to three years ahead of us, paving the way, so that we wouldn't have to do it all on our own.

The increasingly complex customer projects required Nordic to look externally in order to drive continued learning. NTH became important in several regards. Nordic, for once, actively formulated theses that students could work on as their graduate research projects. In this way, they could map and investigate technology trends, following up on developments that Nordic didn't have the resources to pursue by themselves.

In some customer projects, technological knowledge building was an integral part of the project scope. In stating the terms of the project and the resources available, some projects allowed Nordic employees to be bolder in their solutions and to conduct more experimentation, with the effect of expanding the knowledge base from which future projects could be conducted. An additional source of funding for the most experimental development projects was the Research Council of Norway.

One specific trend that became increasingly more relevant within circuit design was the need to integrate analog features into the products. Initially, digital design had satisfied most of the applications that customers required, but analog design opened for taking inputs from physical signals, such as gas concentration or radio signals, and converting it to digital signals for subsequent data treatment. As there was nobody within the Nordic team that had any experience with analog design, it became necessary to look outside of the organization for the necessary knowledge. Trond Sæther was behind one initiative. He enrolled to a doctorate program in analog design, the first of its kind at NTH, while continuing to work part-time at Nordic. By 1991 he had gotten his diploma. Nordic also pushed for NTH to adopt more university courses in the field of analog circuit design, ensuring capable electronics graduates as recruitment material for the microelectronics design industry in Norway for years to come.

Nordic developed ASICs for actors across a wide range of industries, including automotive, aquaculture, medicine and military, with most of their customers situated in Norway. Domestic industrial companies' benefited from local world-class ASIC knowledge, and Nordic's offerings allowed firms to include microelectronics as a vital part of internal product development cycles. Nordic's local presence and close dialog with other domestic actors became a competitive advantage to firms competing abroad.

In the late 1980s, Nordic became involved in a project that intended to develop a European standard for digital TV. The technology behind the standard was named MAC, and specified the way by which TV signals were transmitted through satellite. Such a standard would enable the distribution of European TV channels across the continent, and it would enable pay-TV solutions that would make such distribution more commercially viable. Several large European telecom and electronics companies were involved, including Plessey Semiconductor in England and Philips Semiconductor in the Netherlands. From Norway, Tandberg Telecom and Norwegian Telecommunications' department for Research and Innovation participated.

Nordic took on a central role, and went through a period of expansion in terms of employees on account of the increased need of microelectronics expertise. They went through several large projects within the consortium, and developed technological solutions that were critical to the collaborative activities. The chips that were to reside in the decoder stationed in households were developed by Nordic, and were licensed to Plessey and Philips who did the distribution to end-customers. Through these licensing agreements, Nordic's export ratio increased significantly. The development of the chips was also among the first experiments that Nordic did with regards to designing standardized components.

Tandberg, which at that time was a large technology conglomeration with activities in both television and telecommunications, invested heavily in the collaboration. The contracts that kept Nordic involved were often initiated by Tandberg. In 1991, they regarded some of the technology that resided within Nordic as such a strategic asset that they acquired the company. The intention was to ensure that Nordic's digital TV activities would be better aligned with their own.

Nordic still existed as an autonomous department within Tandberg, and went about pursuing contracts outside of the TV collaboration as they had always been doing. The work that Nordic did with Cryptovision, which was the department within Tandberg that was responsible for the TV activities, was at this point a relatively small part of total activity. As such, the impact that the ownership had on Nordic was less one of technological learning, than it was one of improved professionalism: The reporting structures that was incorporated into Tandberg meant stricter budget routines, better planning, more control. Trond Sæther talks about the lessons from the Tandberg years:

> Apart from the collaboration with Cryptovision, there wasn't a lot of interaction. But the management of Tandberg, especially Jan Kristian Opsahl [CEO of Tandberg], helped bring professional management into Nordic and the Board of Nordic in a completely different way than we had had up until then. First and foremost, perhaps, by setting requirements to costs, and schedules, and such things. They never averted from confronting us when things went differently from how we had said that it would go. Looking back at the collaboration we had with Tandberg, I'd say we learned a lot within areas that we didn't know much about before. The electronics and stuff, those things we had under control, but there were lots of other things. Market and strategy and stuff like that, those kinds of things were provisioned through the collaboration with Tandberg.

The project with developing the MAC digital-TV standard didn't go well commercially, and was eventually phased out. This also meant that Tandberg lost interest in Nordic as a strategic asset. The Tandberg management then prepared for an IPO for Nordic, with the intention of gradually divesting their ownership stake. Nordic went public on the Oslo Stock Exchange's SME-list on March 7th 1996. The timing was good; the ASIC market went through a slump, and the public offering gave Nordic financial strength to get them through tough times.

4.4 New start-ups: Atmel Norway, Chipcon and Gran-Jansen (1995–1997)

Nordic had developed strong relations with Philips after their joint development of the television receiver for the MAC standard. A short while after the completion of this project, Philips again contacted Nordic, with a request for developing the second-generation receiver. As part of the specifications, this new device would need to integrate a microcontroller, because it demanded a significantly higher data flow capacity, and a higher degree of control, compared to the first-generation. Initially, Philips intended to use one of the standard microcontrollers available in the market, the Intel MCS-51, but after recurrent meetings with Philips, Nordic's Chief of Technology and co-founder Frank Berntsen made them realize that the Intel controller would be too weak. To solve the problem, Berntsen developed an entirely new RISC microprocessor:

RISC, an abbreviation for Reduced Instruction Set Computer, is a computer architecture design that has a reduced number of transistors, and hence a reduced number of possible instructions. The processor, named P-RISC, would be licensed exclusively to Philips. This is how Berntsen recalls the process:

> Philips had a license for the Intel 8051 [MCS-51], so we thought that we would use the 8051 [in the microcontroller]. But during a meeting, which I think we had in Southampton, it was clear that the 8051 didn't have enough muscles to do what we had planned. And far from it too - we even thought about using two at the same time, but had to give that up as well. And so basically, in the course of one night, before the next meeting would be held, I made some sketches of how we could make a RISC-like processor, which we could program at higher speeds than the traditional microcontrollers. This was the origin of what was then called P-RISC (...) We would make this processor on behalf of Philips, and the only thing I did in this meeting was to create confidence in our ability to solve the problem.

It was soon discovered that a range of different customers saw great value potential in the product. Nordic eventually decided to use the processor as a component in various customized products, under the new name Nordic Micro RISC (µRISC). The processor, when integrated on ASICs, offered customers the opportunity of doing some in-house programming, which was highly valued. For this first period, Nordic prioritized the µRISC only as a component integral to other products.

In the early 1990s, Nordic would often involve students in research engagements, through summer internships, master's theses and other university related projects. Through such engagements two NTH students, Vegard Wollan and Alf-Egil Bogen, attracted Berntsen's attention, and they came to be involved with the µRISC at several occasions. Bogen, for instance, was engaged in software development in the early generations of the processor, and Wollan wrote his master thesis on the subject. The two students, enrolled to the same electronics degree program, had met at NTH in 1988, and they had bonded on their common interest in science and engineering. The students became convinced of the RISC processor's commercial potential, and began experimenting with improvements also outside of Nordic engagements.

Upon graduating, Wollan in 1991 and Bogen in 1992, both of them began as chip designers in Nordic, but before long they became engaged in sales. Here, the two of them took the initiative to start selling the µRISC as a stand-alone product, and a number of contracts were signed during the first half of the 1990s. Wollan and Bogen, even though they weren't directly involved in the design of the µRISC any longer, were influential in defining the specs through their roles in planning marketing efforts and communicating feedback from customers.

Wollan and Bogen were still highly positive about the value potential of the µRISC, but Nordic was unwilling to finance continued product development. The result was that the young engineers started investigating the possibility of starting a new company based around the processor. Venture capital within the hi-tech sector in Norway was highly underdeveloped at the time, and the duo felt compelled to turn their eyes towards foreign funding sources.

Atmel Corporation, an American semiconductor company that had been a pioneering provider of non-volatile memory chips since the 1980s, had showed some interest in Nordic's μRISC, and had in fact contacted the company about the possibility of licensing the processor. Atmel themselves had already done some experiments with microcontrollers, perceiving it as a natural business extension during a time when memory was increasingly commoditized. They were also of the impression that a broader product portfolio could increase customer loyalty. In 1993 they had launched a product based on the Intel MCS-51, the same as Nordic and Philips had scrapped in favor of the P-RISC. Wollan and Bogen, on the lookout for possible investors, knew about Atmel's interest, and identified the American corporation as a possible source for funding.

In 1995, Wollan and Bogen was granted a fifteen minutes audience with the CEO of Atmel, George Perlegos, in California during which they pitched their business idea. The brief session didn't allow for technical depth, so they focused on the commercial upside, arguing that the product should be able to generate revenues of 100 million USD within five years. Perlegos was convinced, and a contract was signed with Nordic for the transfer of the rights of the intellectual property. The intention was for Atmel to transform the μRISC into a Flash-based microcontroller, which would be named the AVR. It remains some uncertainty as to the origin of the AVR name: It has been rumored to be an abbreviation for Alf and Vegard's RISC processor, but also for Advanced Virtual RISC processor.

At this point, Nordic was in a process with Alcatel, the French telecommunications firm, about developing a new generation of the μRISC, but following the Atmel deal, this engagement was terminated. The contract only allowed for Nordic to do some limited maintenance on the processors for existing customers. Instead, Nordic was hired to prepare the first generation AVR. In fact, the first two versions of the AVR were developed by Nordic, based on specifications provided by Atmel.

Oddbjørn Troøyen, CEO in Nordic since 1989, commented in the aftermath of the divestment that he was proud that Atmel had chosen to go ahead with the AVR, but he was sorry to see his engineers leave (Winge, 1996). He also stated that he "looked forward to cooperating with Atmel, Bogen and Wollan in the future" (p.6, [translation ours]).

And so in 1995, Wollan and Bogen left Nordic to commercialize the AVR microprocessor as a standalone component, starting an autonomous design centre in Trondheim under the Atmel umbrella. Gaute Myklebust, himself an NTH alumnus, became the third person to join, and the three of them would constitute the leadership of the new organization. The establishment marked the first time a Silicon Valley firm invested in design facilities in Scandinavia. The Trondheim department, termed Atmel Norway, would be in charge of product definition and development while the Atmel Corporation provided market access and sales functions through its large marketing system. Products were manufactured at Atmel's fabs in the US and France.

The AVR was an 8-bit microcontroller. The core patency was issued under the title "Eight-bit Microcontroller Having a RISC Architecture" on November 7, 1996. The AVR was both more powerful and more energy efficient than the microprocessors of their competitors, and with the strong financial backing of the Atmel Corporation, the first product reached the market place in 1997. Through efficient marketing and competitive technical solutions, Atmel Norway was successful in gaining market shares rapidly, and was on its way to achieve the revenue goals that Bogen and Wollan had pitched to the Atmel CEO in 1995.

Meanwhile in Oslo, the microelectronics environment at SI upheld their prominence within research on integrated circuits and microelectronics. They were more oriented towards analog design and analog signals than ELAB in Trondheim and had technologically complex development projects ongoing, including collaborations with CERN in Switzerland. In 1993, SI and the other major Norwegian research institution, SINTEF (the parent of ELAB), merged into one entity. SI adopted the SINTEF-name, and the resulting institution became headquartered in Trondheim, with continued operations in both Oslo and Trondheim. Research groups at the two locations, which had been used to separate and locally decided agendas, now had to agree on how to divide the labor and prioritize resources, and the ensuing period of integration became a difficult process.

In 1996, three researchers from the microelectronics environment in Oslo saw opportunities in commercializing some of the expertise that resided within SINTEF Oslo, and decided to start Chipcon, a company dedicated to the design of ASICs. All three of them had master's degrees from the Faculty of Electrical & Computer Engineering at NTH, and had met at the university before starting their career at SI. Geir Førre took the role as the start-up's CEO, Sverre Dale Moen became VP of Sales and Marketing, and Svein Anders Tunheim became the CTO.

Before launching Chipcon, Geir Førre consulted with Alf-Egil Bogen about the start-up plans. They too knew each other from the days as students at NTH, having graduated the same year. Bogen, who was a year into his own start-up project, responded supportively, encouraging Førre to "Go for it!" (Leirset, 2006). He took a position on Chipcon's board, and both he and Vegard Wollan invested in Chipcon, acquiring a 10 % stake each.

All three of the founders were able to acquire significant stakes themselves, with additional support, of 0.5 million NOK, from The Norwegian Industrial and Regional Development Fund (SND), a governmental industry development promoter. SND also provided start-up advice to the inexperienced entrepreneurs.

Geir Førre reflects on the sources of inspiration that lead to the Chipcon start-up:

> I guess Chipcon was a bit inspired by the merger between SI and SINTEF. They cooperated poorly – a lot of friction and much arguing about who should be allowed to do what. I came to realize that it wasn't as much fun anymore. And I was also a bit inspired by Alf-Egil [Bogen] and Vegard [Wollan] – my co-founders knew them as well. Their success was probably contributing to our decision to leave SINTEF in 1996 to start Chipcon. And surely Nordic VLSI inspired us as well. In the beginning, we almost copied their business model, and established ourselves as a design centre that did projects for others.

With regards to the relationship with Nordic, Chipcon positioned itself as a direct competitor, and the competition was fierce in several markets. Like Nordic, Chipcon offered to design ASICs to medium-sized companies that didn't have enough resources to develop circuit design in-house. Chipcon's customers included Norwegian companies such as Otrum Electronics, a hotel-TV solutions provider, and Simrad, a provider of technical solutions for fisheries, based in Horten.

A third company started gaining some attention within the microelectronic environment in the early 1990s. The company, Gran-Jansen AS, had been doing various product development projects in electronics and automation since its establishment in 1981. Petter Gran-Jansen, the founder and owner of the company, had been the inventor of many of these products. He had graduated with a master's degree in electronics, control and computer technology from ETH Zürich, the Swiss science university.

He got involved in microelectronics through an idea he'd had about a mesh network; a system that allowed for various appliances in the home to be controlled wirelessly by the use of radio frequency (RF) technology. In order to make such a product profitable, Gran-Jansen believed that the network's RF functionality had to be integrated into one ASIC. Such a product did not exist at the time. Lacking the necessary competencies in ASIC development, he understood that he was in need of a microelectronics partner. He therefore approached two companies to make inquiries about a possible partnership. First he presented his idea to Nordic, but their contractual offer wasn't satisfactory; all risk and costs would have to be carried by Gran-Jansen AS. Then he contacted Plessey Semiconductor in the UK, but similar contractual conditions made Gran-Jansen refuse there as well.

Gran-Jansen believed that the mesh network he had in mind could take the form of an alarm system for the hearing impaired, relying on lights as a way of alerting. The project aroused interest in two governmental agencies, The National Insurance Administration (RTV) and SND, who saw an opportunity to develop better aids for the handicapped, as well as to cut social security costs. In 1992, they signed a deal with Gran-Jansen AS about the development of such an alarm system, providing Gran-Jansen with project financing of 12 million NOK and 5 million NOK, from RTV and SND respectively.

Gran-Jansen was still in need of an ASIC partner to help him design the essential RF chip, and having refused the terms of Nordic and Plessey, he turned to SI. There he met with Geir Førre and his team of researchers, but the talks didn't go through there either. Petter Gran-Jansen recalls:

> In 1992 I contacted SI and Geir Førre, as I had heard that SI had done some preliminary studies on RF chips. I got a good impression of Førre and his group, but felt unsure about their overall expertise and the funding.

Instead, Gran-Jansen obtained positive response from Norwegian Telecommunications, the governmental monopolist for phone services at that time. Their Research and Innovation branch had some competence on ASICs, and perceived of cooperation with Gran-Jansen AS as beneficial. A product development contract was signed between them, stating that the two parties would be splitting development costs. Activities related to the alarm system would go on internally at Gran-Jansen AS, counting thirteen employees, while the RF chip would be developed and tested in Norwegian Telecommunications primarily.

While in development, Gran-Jansen AS and Norwegian Telecommunications understood that the RF chip could have a huge potential within other application areas. This was the first time that anyone had been able to combine a digital wireless transmitter and receiver in the same chip, a so-called transceiver, which was capable of sending signals at different frequencies. In fact, the development of the chip as a standard component started taking precedence within the project.

In November 1995 the two clients, RTV and SND, decided to exit the project, unwilling to provide additional funding for finalizing the product they had ordered. This decision raised problems for Gran-Jansen AS, strongly in need of funds for continued product development of the chip. A solution was reached when Norwegian Telecommunications, renamed Telenor after industry deregulation in 1994, decided to enter the company as a shareowner. They were highly positive about the prospects of the chip. The responsibility for their stake in Gran-Jansen AS would reside in Telenor Venture, the venture arm of Telenor aiming at developing new companies in the IT and telecommunications industry.

The exit of the two clients required Gran-Jansen AS to go through a downsizing, and only five employees stayed behind. Two of these came from Telenor, bringing ASIC competences with them. All continued development would now go on inside Gran-Jansen AS, and the company would focus solely on the transceiver chip, scrapping the alarm system altogether. The first order for the chip, named GJRF400, was finally secured in November 1997, with the chip achieving considerable attention among potential customers, particularly in foreign markets. The company looked to be on the right track.

4.5 From customer specific projects to standard components (1997–1999)

Towards the end of the 1990s, Nordic and Chipcon would both do a strategic shift away from customer specific development projects towards designing standardized products for wireless data communication. The shift would have a significant impact on the operations of both companies, and on the industry as a whole. The shift had two elements: First; the business model would now be based on selling components to a mass market, creating a huge upside potential due to scalability. Second; low distance wireless communication was chosen, a segment that had interesting prospects, but that was highly underdeveloped.

As for the first element, the shift was a logical one with regards to business profitability. When selling ASIC consulting services, your profits are proportional to the number of employees, because the development projects are dependent on active human involvement and expertise. The customer typically pays per project, and liquidity might be tight in periods of low activity. However, the pressure for capital investments is rather low, because the customer often carries the cost of project-specific tools and research. An additional characteristic is that, because an ASIC is produced on behalf of a specific client, the client will be the owner of the products. This implies that reselling the design normally would be a breach of contract, and in many cases infeasible, because of the specificity of the product design.

Conversely, producing standardized products is a very scalable operation. Product development might be capital intensive, but as soon as you have arrived at a design, the cost of manufacturing one additional product is low, creating a significant upside potential when combined with an appropriate pricing model. The decision to start designing a standardized product was thus based on an intention of tapping into the needs of more than one customer in the market, to gain large volumes and scale the output of the company R&D. Karl Torvmark in Chipcon reflects on it in this way:

> How many dollars you can earn per employee, that's what it all amounts to. So, it was such an assessment that convinced us to change focus. In many ways, consulting is good in the early stages. Chipcon have, with a few exceptions, reported profits. You're not able to do that if you go directly in as a product specific firm.

As for the second element: The fact that both companies decided to focus on short-distance radio frequency (RF) solutions could have historical roots. Norway had been a prominent country in radio technology after the world war, with The Norwegian Defense Research Establishment (FFI) conducting basic research, and NERA being a strong commercial actor producing radio equipment. In the 1980s the Nordic countries also held a strong position within mobile telephony technology. SINTEF-scientists were central in the development of the radio part of the GSM-standard, and Nokia in Finland and Ericsson in Sweden rose to become industry heavyweights based on GSM knowledge. Norway hadn't been able to match their neighboring countries in benefitting from the early GSM activities, and commercial interests were on the outlook for the next big thing.

SINTEF in Oslo had been an important provider of applied research to the radio communication industry. Customers included NERA who integrated SINTEF-research into their satellite communication products. The three Chipcon-founders themselves had gained some direct experience with radio communication during their SINTEF years. In 1995, only one year before the start-up for Chipcon, they had completed a project funded by the Norwegian Research Council in which they designed an ASIC for RF-applications, with operating frequencies from 20 MHz to 1 GHz (Moen, Førre and Tunheim, 1995). The solution wasn't directly comparable to the products that Chipcon would go on to design, but it did contribute to equipping the entrepreneurs with some basic knowledge on ASICs with RF-applications.

A more direct contribution was the ASIC projects that the companies had been employed with for several years. Some of the projects they had completed included elements of radio communication functionality, and this resulted in the engineers gradually building competencies on RF solutions. In fact, the two first standard components from Chipcon were identical to those provided to a customer on an ASIC-contract. When Chipcon saw the possibility of creating a standardized product out of the ASICs sold to this client, they approached him with offers of contractual benefits and got a green light on taking it to mass market.

The companies anticipated the emergence of a market for low-power RF chips, much due to technological progress in combination with prospects for increasing customer demand. At the time there were few, if any, standardized products for radio communication in the market, and existing demands were usually covered by expensive ASIC-projects. There were no major corporations that had positioned themselves yet either, and so the companies detected an opportunity to gain foothold before the market would accelerate. Trond Sæther describes Nordic's technological assessment in the following way:

> Radio was an area we had been considering for a few years and which we saw would come to be technologically feasible. Back then, radio was associated with mobile phones and GSM, and larger things that could cost thousands of kroner, but we saw that with the proper use of technology one could get the price of such a gadget down to a much lower price than that - maybe down to a few dollars. (…) We evaluated our own technology skills and what we saw of technology internationally, and came to the conclusion that it probably would be possible within a few years.

Nordic started the design of the first standardized short-distance wireless data communication circuit in 1997, and the chip was released to market in late 1998. Chipcon had gotten to the market even earlier with their radio chip, SmartRF, in May 1998. During the same period, a number of international firms released their own chips, including Motorola, SGS Thomson and RF Micro Devices, but the Norwegian companies' solutions proved highly competitive.

For Nordic, radio chips weren't the only alternative that was considered. Trond Sæther continues by describing the process of finding the most prospective area of focus:

> We had other ideas as well [other than radio], and they were presented to the Board. We were in a situation where we had a set of possible scenarios to consider, and ultimately wireless communication was found to be the strongest case. What was thought to be the second strongest case was data converters. In fact, our internal data converter competencies were probably stronger than our wireless competencies at the time.

Nordic's knowledge of data converters dated back to the end of the 1980s, when Trond Sæther conducted his PhD in analog design at NTH. A second PhD program, conducted by Geir Sigurd Østrem, a Nordic employee, in 1993, further strengthened their competencies on this area, and in the years to come a number of related master theses, under the supervision of Sæther, Østrem or other competent persons from Nordic, were conducted.

In 1998, Nordic's data converter competence was grouped into its own department, and it was decided that its solutions would be licensed out for use by other firms. Such a business model, so called IP licensing, was common among several semiconductor companies. The ASIC-operations would continue within a third department. These activities, in addition to proceeds from their 1996 IPO, would support Nordic financially through the transition.

Atmel Norway had already gone some ways in providing standard solutions, and the sharing of their experiences would be helpful to the transition of the ASIC-firms. In particular, Alf-Egil Bogen, Atmel Norway-founder, would advise Chipcon through his position on the Chipcon board. In fact, in 1999 he stepped up to become Chairman, helping Chipcon make a successful transition. Bogen would eventually leave the Chipcon board, in November 2002, at a time when Atmel themselves started experimenting with integrating RF-functionality in their microcontrollers, because the two companies might end up in situations of direct competition.

Gran-Jansen AS, too, was earlier to the idea of offering their proprietary solutions to a mass market, and their RF chip would in fact compete with Nordic's and Chipcon's. But Gran-Jansen AS's business model differed from theirs: Gran-Jansen was relying solely on invested capital and sales of already finalized standard components to finance marketing and continued product development. The result was considerable deficits for several consecutive years, and in 1997 Gran-Jansen had to go through a new round in order to secure additional funds. An attempt of raising capital externally failed, much due to the high valuation that Petter Gran-Jansen and Telenor Venture expected. When the need for funds became acute, Telenor Venture was willing to provide new capital, but only in exchange for a substantial increase in their stake in the firm. Petter Gran-

Jansen strongly opposed the dilution of his own stake, and in 2000 he exited the company entirely. Accordingly, in July 2000, Gran-Jansen AS changed name to BlueChip Communications AS.

4.6 Falanx Microsystems, and the continued influence of NTNU (early 2000s)

NTH had proven central to the early stages of the development of the microelectronics design industry, both through its function as a research institution and in educating engineers who would be recruited by industry companies. In 1996 NTH was one of six building blocks in the establishment of the Norwegian University of Science and Technology (NTNU). This resulted in some organizational changes, but as NTH was by and large the only engineering school part of the merger, their operations were mostly unchanged. Entering the 2000s, NTNU continued to be of influence as a recruitment source even though the role as a research institution was of diminishing importance to the commercial actors.

NTNU had the responsibility for all higher technology education in Norway, and more than 1200 student graduated with a master's degree in science in 1996 (Kjærvik, 1997). 30% of these students received their diploma from the Faculty of Electrical & Computer Engineering. This faculty constituted of the two departments that was most relevant when seen from the microelectronics design industry's point of view: The Department for Physical Electronics, and the Department for Computer and Information Science. Several graduates from these departments had risen to prominent positions within the industry, or they had been part of creating it themselves. The two Atmel Norway founders, the three Chipcon founders and the four Nordic founders had all received their diplomas here.

One arrangement that was used by the companies in order to make use of resources at the university was the authoring and supervising of master's theses. Seven out of ten diplomas at the Department for Physical Electronics were written for a firm in the industry in the period between 1998 and 2005, two thirds of which were written either for Nordic, Chipcon or Atmel Norway (NTNU, 2006). The arrangement was beneficial for all parties involved. The companies would get to know and test students' skills before they graduated, and they would often use these theses to investigate research areas outside of their current scope, thereby explore prospective product ideas. The students would get to know a potential employer, in addition to acquiring relevant industry knowledge, getting a career head start. Frank Berntsen of Nordic elaborates on the importance of master's theses as a channel for experimentation and technological learning:

> If we [Nordic] are willing to put an effort into it, then we will be able to explore a design space that we would either have to gamble on, or not do at all. In fact, many times the theses are considered failures from a technical point of view, but we have still learned a lot from them. Some of the best master's theses I have seen might have been so-called

> failed theses, but they have provided us with so much knowledge so that we manage to do it correct next time.

Individuals that taught and met students throughout their NTNU-studies also played an important part in motivating and raising awareness among the student group. Contact with the industry had been a long tradition for the department, with several NTNU professors having engagements within industry companies. Trond Sæther, for example, combined a position on the inside of Nordic with a professorate at NTNU. During his time at NTNU he was central in the inception of courses that provided students with applicable semiconductor knowledge. Gaute Myklebust of Atmel Norway is another example: He held a position as lecturer at NTNU on the subject that had also been the focus of his PhD. Oddvar Aaserud, the first CEO in Nordic, left the firm after nearly six years to start a professorate at NTNU.

Dr.-Ing. Einar J. Aas, part of ELAB's early microelectronics activities in the 1970s, had began as a professor at NTNU in 1981. From his position at the Department of Electronics and Telecommunication he became one of the major inspirational figures for students. He had a central position in the establishment of the Circuit and System (CAS) design group at the department, and was close to students, both through a number of courses and as supervisor for master's theses and dissertations. He was leader of the CAS-group for three decades. Aas was also the driving force behind DAK-Forum, a forum for computer-aided design, which allowed companies to discuss product and market trends. The DAK-Forum rose to become one of the most important national networking arenas in the industry. In 2002 he took a year off from NTNU and worked for Atmel Norway in the field of test design. At this point, three out of four employees in Atmel Norway had attended his courses.

In 1998, two computer science students specializing in hardware, Jørn Nystad and Borgar Ljosland, started discussing a new design for a graphical processing unit (GPU) for computers. The idea was the result of the students' inquires into why the clock speed of the modern CPUs had been increasing so much faster than that of GPUs. The two students presented their idea to professor Aas, who was intrigued by the idea. The students would be occupied with designing the GPU product, named Mali, throughout the rest of their studies, with many of their curricular engagements, including their master's theses, dedicated to the development project. This was largely made possible by the efforts and support from professor Aas, and professor Lasse Natvig, from the Department of Computer and Information Science.

In April 2001, a firm called Falanx Microsystems was established, founded by Nystad, Ljosland, and three fellow students; Mario Blazevic, Robert Mæhlum and Edvard Sørgård. Sørgård was the only one enrolled in the physical electronics program, with the rest being enrolled for a master's in computer science. As soon as they graduated from NTNU, the young entrepreneurs got located in offices at Gløshaugen Innovation Center, an NTNU incubator.

Ljosland would credit one of professor Natvig's courses, the Computer Architecture and Design Group (commonly referred to as the DM-project), with inspiration to their start-up. According to Ljosland, the course, giving the students practically free reins to solve a general problem by applying theoretical models in a laboratory setting, had demonstrated to the students that it was possible to create a product from the highly abstract theories that they were taught in class. But Ljosland also emphasized that the start-up was an initiative that largely came from the young students themselves; that the time felt ripe for hi-tech entrepreneurship, and that the knowledge that went into the product was a result of a fascination for microelectronics that started long before their inauguration at NTNU. In fact, Jørn Nystad, the person who was credited with the technical aspects of the product idea, had been designing CPUs since he was twelve years old.

During the fall of 2000 the five guys won their initial start-up capital in Venture Cup, a national business plan contest for student, but these funds were very limited. After less than one year of operations one of the founders, Mæhlum, left the firm from his position as CEO, with Borgar Ljosland taking over. During the next four years the remaining entrepreneurs had a hard time convincing venture capitalists to invest in their company. Some help in product development came from Nordic, who was curious about the new firm and interested in helping them get started. Trond Sæther had taken on a board position, and Frank Berntsen interacted with the founders on technological aspects. At a point in time when Falanx was looking to test their layout, they entered into an agreement with Nordic about the use of some of their equipment, which Nordic was interested in testing themselves. Borgar Ljosland describes the process:

> Nordic had invested an awful lot in tool and tool chain, which is what a chip company had to be good at. (…) Frank Berntsen [CTO of Nordic] did not have a design that was large enough to really test his tool chain. So then we got in place a deal where Nordic and we worked together. To license a layout tool - it was too expensive for us to have access to such tools. Then we got a deal where Nordic hardened Mali. They ran through the synopsis and layout to get the actual physical space, power consumption, the entire simulation area. So it was a win-win situation for Nordic and us. It was a collaboration. It was commercial interest in it for us since it enabled us to actually license the IP. Before you validate it, you cannot do that. You shouldn't do that. So we got that funded through this.

Trond Sæther talks about the collaboration from Nordic's point of view:

> We helped them with access to very expensive data development tools that they would not have the opportunity to gain access to by themselves. (…) Occasionally we made these kinds of agreements, when we found something that looked exciting, something we could be passionate about. Perhaps it was something that we perceived as interesting technological experiments, and then, if we had any excess capacity, we often made an agreement. What we did for them in this case was to help them a little with the design; we did the layout in our offices.

In effect, yet another company was added to the microelectronics design industry. This also meant that one more company was to compete for the brightest among the NTNU students. The consequence was some genuine worries about the absolute number of new graduates, and to what extent it was sufficient in supporting the growth of the industry as a whole. The number of high school students that applied to technological studies in general, and electronics programs in particular, was gradually decreasing in the early 2000s, and it was obvious that the situation was far from beneficial. The companies, occasionally through joint initiatives, started advocating the need for more science students, and met with university administrators and politicians. The trends proved difficult to turn around.

4.7 Growing international success (1999–2005)

The early 2000s saw increasing international success for the companies. At this point, Atmel Norway, Nordic, Chipcon and Falanx had all positioned themselves to capture market shares selling components to producers within a variety of industries. Their market approach had many similarities. For one, the companies developed products with distinct specifications that allowed them to differentiate themselves in the market place. In particular, the products often boasted of low power consumption, in combination with competitive technical performance. Also, all the companies went wide in searching for customers, establishing global sales networks.

Jo Uthus, senior director in Atmel, reflects on the underdog positions of the Norwegian players:

> You are in a very special situation when you get into a market that is much consolidated. (…) You are in an underdog position where you want to prove something, and when you want to prove something you can achieve quite a lot. (…) You don't limit yourself to operate only in Northern Europe, or Scandinavia, or regionally in Europe, but you open up and offer yourself to the world. Of course, you face an extremely tough market, but you can find reference customers everywhere, and find niches and verticals that are sure to be in need of the technology you provide. You have to start with something that differentiates. (…) With regards to the AVR, when it was launched in the 90s, it was a factor of 1 to 4 on performance, which was what counted back then. Then we became a world leader in power consumption and system integration. Without such a differentiated offering, we wouldn't have succeeded. If you create a "me too" which is equally prized as other products, you'll get nothing but a shrug.

This entry into global markets coincided with difficulties within the IT industries, the so-called dotcom-bust, and many of the major component manufacturers struggled. Still, several of the Norwegian hi-tech start-ups built market shares throughout the difficult conditions.

Atmel Norway was the first to capture significant sales in the global market. They were highly competitive on price, with the incumbents, often attempting to secure significant margins, pricing their products so high that it provided entry opportunities. They also exploited their underdog image, in addition to building credibility among decision-making engineers. The essence of their approach was caught in an informal slogan that was used occasionally: “Engineering products, by engineers, for engineers”. An online community, called AVR Freaks, was established and became a huge success over the next decade, reaching more than 250.000 users by 2011. The forum became the preferred online meeting place for people interested in the development of AVR technologies and tools, with programmers discussing and sharing their own experiences.

With the AVR 8-bit microprocessor as their basis, and large production capacity through the facilities of the Atmel Corporation, Atmel Norway was prepared to be a trustworthy and value-increasing supplier to the global electronics players. In 2000, the breakthrough contracts were signed: In March, Sony, the Japanese company, signed a contract for the delivery of chips controlling power supply in Sony’s products. Then, in June, Atmel Norway landed a contract with Ericsson, the Swedish company, to provide microprocessors in Ericsson’s top cell-phone models T18 and T28. Both contracts had required a prolonged period of collaborative research activities.

The Trondheim department invested heavily in R&D, at a higher level than competitors such as Microchip Technology. Often they allowed for key customers to participate in the product definition phase. Jo Uthus elaborates on their approach to development and customization:

> Early in the product development phase, we are working closely with major customers. When the product is fully developed, and has some derivatives of microcontrollers, then it goes into the mass market through distribution. At that point we make adjustments based on the trends that we see, and not necessarily in direct dialogue with individual customers. (...) If you can accomplish to generalize what one customer want, and then make it widely available, then you have hit the nail on the head.

Gradually, Atmel Norway emerged as Atmel Corporation’s most important design center. While the other parts of the corporation faced severe market difficulties in the aftermath of the dotcom-bust, Atmel Norway saw year on year growth figures of up to 40%. In 2001, Atmel Norway’s operations were officially regarded as a business unit, the Microcontroller Business Unit, and the large growth required the establishment of offices in strategic locations across the globe. Soon the Trondheim department administered offices in Finland, China, India and California. Wollan were to be vice president of the business unit, and Bogen relocated to California to be CMO for the entire corporation. Both had seats on the Atmel executive board.

On the Norwegian electronics fair e01 in 2001, Chipcon released their groundbreaking new chip, the CC1000. Built entirely on their new technology platform SmartRF02, the CC1000 was one of the first RF-chip to use CMOS silicon construction technique. This was perceived to be a highly ambitious but risky move: Traditionally, radio chip producers had perceived of CMOS as a technique lacking in analog features, and BiCMOS had been dominant, also by Chipcon on their first radio chips. BiCMOS integrated CMOS transistors and their advantages in digital logic with bipolar junction transistors, the original transistor type whose properties were excellent for analog amplifiers. Due to drawbacks of the BiCMOS technology, in particular its high power consumption due to leakage, the industry anticipated a switch to CMOS. The shift emerged gradually as technological advancements made the technique more commercially viable.

Cambridge Silicon Radio, a British fabless semiconductor company, was pioneering in this shift, and became leading within their market segment; Chipcon was first amongst their competitors, and CC1000 attained advantages including lower power consumption, higher packing density, lower production costs and easier chip integration. The CMOS technology would be the industry standard before long, and Chipcon would look back at their early decision to switch as one of their most important strategic decisions.

The CC1000 was a huge market success, and Chipcon experienced magnificent growth, with both revenue and profit growth exceeding 100% year on year several years in a row. The company had gone through the shift to standard components with profits every year, rapidly building down their reliance on ASIC operations. Employee moral was high in their offices in Oslo Science Park, next to the University of Oslo; all employees owned stocks in the company, and nobody had quit during five years of existence.

Large deals were done directly with the customers, with Chipcon, like Atmel Norway, often seeking out pilot customers to contribute in the product definition phase. Chipcon opened sales offices in Silicon Valley and Stuttgart, while smaller contracts went through a distribution network spanning 24 countries around the world. In particular, Asia became an important market. Chipcon's chips could be found in products ranging from wireless gamepads for Nintendo, Playstation and X-Box, to alarm- and security solutions, and devices related to Smarthouse.

Nordic was slower to mass market than Chipcon, much due to their extensive efforts in product development. Having developed the first RF-chips on lower frequencies, it was decided to initiate development of chips on 2,4GHz in August 2000. The 2,4GHz frequency band resided in the open Industrial Scientific Medical (ISM) band, which allowed for license-free usage and significant scaling due to the consistency across international markets. The choice of frequency would also be decisive for which characteristics it was possible to integrate into the radio chip. The 2,4GHz band in particular, enabled a range of new applications, and was highly favorable for short-range, low-power communications systems. Also, transceivers on 2,4GHz had only recently become technologically viable, and the market space was largely uncontested, with the large international actors occupied with frequency bands for GSM and other telecommunications technologies. Trond Sæther summarizes the process of deciding on 2,4GHz in the following way:

> When we started [with RF chips], back in 1996, 1997, 2.4 GHz was utopia; it was out of reach financially and technologically. So we had to start with the European 433 MHz

> band and the American 315 MHz band - later also European 868 MHz and American 915 MHz. However, because these bands are local and not global it is difficult to obtain sufficiently large volumes. That didn't happen until 2.4 GHz, which is a worldwide band. There are a few local versions of it too, but mostly you can say that 2.4 GHz can be used everywhere on the globe. And only then are the volumes large enough to get the costs down to a level where you can get this ubiquitous - available everywhere. It costs almost nothing, it uses little power, it is reliable.

For a few years, these large R&D investments and a slow market burdened Nordic's financial results, with every year from 1999 to 2003 ending with large deficits. In particular, the targeted wireless trends weren't picking up as quickly as they had anticipated. Investors required concrete actions, and this would include the hiring of a new CEO, Svenn-Tore Larsen, in 2002. Larsen came from a position as Area Director for the Nordic region in Xilinx, a Silicon Valley company which had pioneered the fabless business model. In addition, Nordic closed down its offices in Bergen in 2002, after less than two years of operations. In 2003, the company found it necessary to carry out a 15% downsizing.

Their target market gradually saw improvement throughout 2003, as more and more consumer electronics producers confirmed that they would integrate wireless features in products that had been wire-based traditionally. As Nordic could offer products that were leading on performance, value-added features and power consumption, they were able to arouse interest in companies that were looking for a RF-solutions provider to accompany them into new product realms. Svein-Egil Nielsen, chief executive of sales at the time, comments on Nordic's approach to getting a foothold among large producers:

> If you have an interesting product, then you are allowed to come in and tell what you have. You must of course call some and nag a little and do the sales job, but if you have accomplished to make something really interesting, and you have managed to pinpoint a customer that the product might be interesting for, then it's usually foolish for that customer not to listen to you - just in order to construct a picture of the world, and to map what alternatives there exist. I like to think that customers are interested, because it gives them a better idea of whether to push prices down, and the more you have to choose from the better it is. So you're often allowed entry into a company.

The contract that would be considered their breakthrough came in November 2003 with Logitech, a leading global provider of PC accessories headquartered in Switzerland. After several months of dialogue, the first contract was signed on a large volume shipment of chips to gamepads. The contract, though the customer was not disclosed, was in the Annual Report for 2003 (Nordic VLSI, 2004) referred to as "strategically vital" (p.4); the partnership was considered "crucial to Nordic VLSI" (p.7).

The initial contract, successfully expedited by Nordic, also served as a beachhead into Logitech's prime business areas, namely that of PC keyboards and mice. In 2004, Logitech chose Nordic's RF-solutions for its new cordless mouse, the V500. Described as the "Porsche of notebook mice" (CNET, 2004), the V500 received much attention and praise on its release. It was decided that the deal was to be made public, resulting in Logitech making several official statements declaring their contentment with Nordic's professionalism and technological knowledge. Vice president of marketing for retail pointing devices in Logitech, Ashish Arora, stated that the release of the V500 "could not have happened without our close collaboration with Nordic Semiconductor" (RF Globalnet, 2004), and that Nordic had been an "exemplary technology partner and a highly responsive supplier". The praise had an important promotion effect, portraying Nordic as a trustworthy supplier that could handle large scale contracts.

2004 became the first time that Nordic reported profits on their new business model. CEO Svenn-Tore Larsen declared that Nordic had become a "leading global semiconductor supplier" (Nordic VLSI, 2004, p.4), and this was accompanied with a name change, in 2004, to Nordic Semiconductor. The number of contracts increased, and they built a strong presence in segments such as sports equipment, toys and industrial applications, in addition to PC peripherals. In a similar fashion as Chipcon, the larger sales were mostly conducted by Nordic's own sales force. They had presence in Oslo, to be close to potential customers, and in a new sales office in Hong Kong. Smaller sales went through independent distributors in a sales network that spanned the globe. Strict focus was kept on lowering prices, visible in the refinement of their fabless model.

Chipcon and Nordic thus captured positions as world-leading providers of RF-chip solutions. Just like it had been during their time as ASIC providers, the competition between them was heated in many markets. This provided a highly stimulating environment, pushing both firms to be innovative and responsive to the opportunities in the market. Geir Førre comments on the head-to-head competition:

> The fact that we [Chipcon] were successful probably made Nordic step it up. There was intense rivalry between the two environments - extreme competition between Nordic and Chipcon in the course of ten years, and this was probably an important reason for why both companies ended up doing so well. The competition between two companies that are located in geographical proximity – it contributed in making the companies world leaders in slightly different areas.

Noteworthy, the communication between the two firms were practically non-existing, with the exception of sporadic meetings on electronics fairs and other industry events. Chipcon was located in Oslo, while most of the Nordic employees were seated in Trondheim, so informal encounters and personal interactions were limited as well. There wasn't recorded any Nordic employees switching to Chipcon, nor vice versa. The two competitors were virtually isolated from each other.

The third Norwegian provider of RF-chips didn't do as well the others. In the beginning of 2001 BlueChip, previously Gran-Jansen AS, had launched a product that was intended to compete with existing Bluetooth solutions. According to specifications, this new chip would cost less and consume four-fifth the energy of the competing products. But the market didn't respond as anticipated, and the company struggled to gain volumes. In late 2001, BlueChip decided to license their technology to Micrel Inc., an American manufacturer and reseller of microchips. Only some hundred thousand chips had been sold during the previous three years, and getting under the umbrella of a global semiconductor actor would hopefully help in gaining market shares. The partnership didn't resolve BlueChip's financial difficulties though, and in 2004 they were incorporated as a development department of Micrel Inc., changing name to Micrel Norway AS in June 2004. The firm still employed about ten people, as they had done since the late 1990s, but this number gradually declined from 2005 onwards, and the firm was finally dissolved in 2009.

Falanx experienced increasing interest from international markets. It began with the strategic decision of focusing on a niche of the market for graphical processing units, instead of continuing the competition against Nvidia, the number one provider of GPUs for the PC market. It was decided to make an attempt on becoming a supplier to the cell phone market, anticipating a growing demand for technologically advanced games on mobile devices. Falanx would design the technology, and then license it to the major cell phone providers. Borgar Ljosland reflects:

> We put on the visionary glasses to see where the mobile devices were heading. What about the markets in which GPUs doesn't currently exist; we can do something there. And so we focused on mobile. Changed the business focus from making the chips to start licensing, which in and of itself was a relatively new thing in the semiconductor market.

In 2003, Falanx raised a small but important sum of money from IT Fornebu, a Norwegian incubator for hi-tech firms located in Oslo. Part of the conditions was for Borgar Ljosland, CEO of Falanx at the time, to accept having Jan Bjerke as his mentor. Bjerke was highly experienced in the Norwegian IT industry, and was to travel internationally with Ljosland to secure the company's first contracts, and to keep looking for funding sources.

The Falanx founders occasionally sought advice from the entrepreneurs that had succeeded before them. They turned to Gaute Myklebust, Alf-Egil Bogen and Vegard Wollan for business advice, feeling that the Atmel Norway founders had gone through similar steps in their pursuit of competitiveness in technology markets. Frank Berntsen of Nordic kept providing technical advice, while Trond Sæther helped out with industrialization aspects through his board position. As Borgar Ljosland puts it:

> There are indeed very few people who actually understand what you're talking about. You can sell a product, but in order to build a company, you need to have a gut feeling in order to have a meaningful conversation about specific issues, because one issue never has only one solution. To understand this you need to have been through it yourself.

2004 became the year when solid venture capital was finally secured, and product development and international marketing could be accelerated. Falanx' products had advantages similar to the successful products of the other Norwegian actors: Mali had low power consumption and low production costs, without compromising on graphical performance. The first licensing partner was secured in August 2004, through a contract with Emblaze Semiconductor, an Israeli fabless semiconductor company producing solutions for cell phone multimedia transmission. Soon followed contracts with other semiconductor companies, including Zoran Corporation and Agere Systems, creating, in Ljosland's words, "a commercial momentum" of increased credibility among potential customers.

In the mid-2000s Falanx initiated strategic partnerships with a number of gaming companies to get a development platform for mobile games matching those of game consoles and computers. The reason for these collaborations was that both parties would benefit from accelerating the need for good graphics on mobile handsets. The interest of device manufacturers, Falanx' actual customers, was to a large extent dependent on what happened at the application level of the handsets: If the need for high-quality graphics emerged in this market, then Falanx would be well positioned for gaining market shares.

During this period, the industry's dependence on domestic demand declined drastically. Sales to domestic actors were now a nearly negligible share, with the exception of some remaining ASIC-activities in Nordic and Chipcon. The primary reason for this was that the industry players had turned their focus to mass-market device manufacturers, which was a segment that was practically non-existing in Norway.

The domestic firms that had been customers of Nordic, Chipcon or other smaller ASIC-providers didn't necessarily have to start sourcing such services abroad. Increasingly they found their needs covered by other products. For one thing, some of the ASIC demand was replaced by demand for field programmable gate arrays (FPGAs), an integrated circuit that can be programmed by the customers to cover their specific needs. FPGAs chips generally have a much higher unit cost when compared to ASICs, but the ASICs' design costs are added on top, making ASICs more costly than FPGAs for the low volumes typical of Norwegian customers. A second important factor was that advancements in microcontrollers made them capable for employment in a larger range of application areas.

4.8 Involvement in industry consortia (mid-2000s)

Chipcon and Nordic would both be involved in standardization collaborations on their way to gaining shares in the international market place. In general, within the wireless communication segment, collaborative efforts that promote industry standards are widespread. Large consortia such as Bluetooth and Wi-Fi are backed by most of the major industry players. Whereas promoting your proprietary solutions might be valuable in some contexts, for example when seeking to uphold a monopoly situation in your product domain, such a situation is hard to obtain, because proprietary solutions require you to supply your chip to both ends of a radio connection. Industry standards, on the other hand, allow you to tap into networks of compatible devices, often resulting in a significantly larger market size. Karl Torvmark, engaged in the startup of Chipcon's standardization activities, reflects on the rationale:

> I think we've always believed that if it is successful, then it is a greater potential in what is becoming a standard, compared to proprietary solutions. When you have interoperable equipment, the market just gets bigger. So even if you end up with more competition, and you end up taking a smaller piece of the cake, then the cake gets bigger. This has been the main rationale for engaging in standard stuff, instead of just operating proprietary.

Similarly, Svein-Egil Nielsen in Nordic comments on their attitude to standards:

> So, proprietary technologies may work for a while, because it could be better than a standard. Cheaper, better on power or something else. But in the long term everyone seeks towards a standard in a technology context. One could almost say that it is an inevitable path, seeking towards standards for large volumes. If you look at large companies with huge volumes in their products, they seek for standards in order to ensure multisourcing, to ensure a more long-term perspective for the technology. These were the thoughts we had – that eventually everything moves towards a standard.

In a standards consortium, the goal is to decide on a standard protocol that will end up gaining universal status in the particular industry. In making this possible it is important to get key participants engaged in the development to make sure that the end-solution is something as many actors as possible will stand behind. The development of a standard is often done in working groups where firms are eligible to contribute with technology development and protocol definitions. The best technical solutions often win through, as actors want to promote the most capable functionalities.

Chipcon began experimenting with wireless standards first, in the early 2000s, through a development project for a Bluetooth solution. The project was eventually abandoned by Chipcon due to the perceived crowdedness in the Bluetooth market place. Instead they decided to promote the solution as proprietary. Geir Førre looks back at the strategic move:

> I'm not sure if it was the right decision, because I think the solution we had was in fact the best. Perhaps we didn't have as strong a self-image back then. Instead it was more of a "we won't pull this off" attitude. Given that all of the major players had technology themselves.

Later, it was perceived that a more appropriate match would be to promote the solution on the ZigBee platform. ZigBee, a competitor to the Bluetooth standard, but differentiated in terms of lower data rate and longer reach, was more focused on applications that was already a priority for Chipcon, including applications related to industrial processes and home appliances. Chipcon then initiated a technology collaboration in which Ember, an American software company, took responsibility over software solutions and Chipcon did the hardware. Chipcon did the necessary adjustments to the solution that they already had in the pipeline, and released their

CC2420 in November 2003. Even though it wasn't the first ZigBee-enabled solution on the market (Freescale Semiconductor was first), it was conceived as the best one technologically, and it was soon to be regarded as the de facto standard, enjoying a status as the benchmark ZigBee transceiver solution.

In 2004, Chipcon decided to develop software services in-house, instead of continuing their collaboration with Ember. In order to acquire the necessary skills, they bought an American software company, Figure 8 Wireless, headquartered in San Diego. Sixteen employees came with the acquisition; in total Chipcon now employed almost a hundred people. The acquisition was intended to help Chipcon offer customers a complete ZigBee platform, integrating software and hardware, being the first company in the world to do so. The CEO of Figure 8 Wireless took the position as Chipcon's CFO. Geir Førre reflects:

> Software became more and more important. These radio protocols were becoming more complicated. It was a big obstacle that the customers had to develop all the software themselves. So we were very early in thinking that the product we were supplying had to be as complete as possible, not just hardware, but software and system. And so we bought the American software company in 2004.

Karl Torvmark would look back at the acquisition as a "faster way to acquire the necessary knowledge", and he would consider it a smart move when the alternative was "to start building it from scratch".

The market for ZigBee enabled products was growing slower than anticipated. The consequence was that Chipcon's own ZigBee product never contributed as much to revenue growth as one had anticipated. But the promotional effect was significant. In 2005, the ZigBee Alliance constituted of 180 companies, up from sixty the year before, and companies from every stage of the product value chain were represented. In June of that year, in Oslo, Chipcon hosted the ZigBee Open House, the annual ZigBee conference where the member firms met and discussed the continued development and promotion of the standard. Førre proclaimed that the "conference would put Oslo and Chipcon on the technology world map" (Kristiansen, 2005, [translation ours]).

Nordic began their involvement in standardization activities a few years after Chipcon, in 2005. It started with an inquiry from Nokia, the Finnish cell phone producer, about the inclusion of Nordic in a cooperative effort in developing a low-energy wireless standard, called Wibree. Besides Nokia, global players such as Broadcom, CSR and Seiko Epson participated in the Wibree Alliance, and Nordic saw benefits from getting exposed to such industry heavyweights, also for promotional reasons.

Wibree was an effort to make up for one of the major drawbacks of the Bluetooth standard; its high power consumption. While Bluetooth required a continuous connection, Wibree was developed as a standard that could be on air for brief periods, thus obtaining lower power consumption. Nordic was seen as a beneficial contributor due to their knowledge on precisely those kinds of radio connections. Originally intended to take advantage of technology that was already in cell phones, Nordic contributed to the decision of attempting connectivity with the Bluetooth standard. Using the cell phone as a hub through which you could connect all kinds of new devices, opened up for the potential of a huge market, in the midst of the worldwide cell phone trends of increased device sophistication and major phone penetration.

In 2007, Bluetooth Special Interest Group Inc. (Bluetooth SIG) acquired the Wibree technology from Nokia. Bluetooth SIG, the organization owning the trademark and overseeing the development of Bluetooth, realized that in order to strengthen the Bluetooth standard, the inclusion of a low power technology was crucial. Nordic followed the technology transfer, and became central in the development of what was renamed Bluetooth Low Energy (BLE). CEO Svenn-Tore Larsen described the transition as “the most important event in Nordic’s history” (Nordic Semiconductor, 2008), because it would open new market segments through increased interoperability.

Being one of few that actually had experience with this kind of low power consumption, Nordic’s voice was heard within Bluetooth SIG, and they had great impact on the standard specification work. Nielsen says:

> When working with standards, the best technological solution will win the discussions. It might be politics, but the important thing is that if you can argue that your solution is better from a technology point of view, then that solution should prevail.

Nordic participated in various Bluetooth working groups, including the architectural review board, and different market segment groups. Chipcon too got involved in the BLE work, though not to the same extent as they did with ZigBee. Some interaction between the two firms took place through their common interest in the success of the BLE. Svein-Egil Nielsen of Nordic comments on the situations where competitors meet in standards organizations:

> With standards, the challenge is that it is easier for competitors. More competitors enter rapidly, there is no doubt about that. When looking at our direct competitors in BLE, they vary in their degree of participation in the standards work. There are indeed some who enter with technology - some brought in a lot of interesting technology, which I think in hindsight we should appreciate. We didn’t anticipate it. You almost have to trust that when the group is larger, then more smart people are thinking. But there are surely some free-rider problems too, where some participants don’t contribute. Even though in principle, if you do not contribute, then you are a bit disadvantaged with regards to implementation as well.

Falanx too became involved in, and benefitted from, standardization work. In 2003, they joined the standardization consortium Khronos Group, dedicated to “connecting software to silicon” and create royalty-free “open standard APIs to enable the authoring and playback of rich media on a wide variety of platforms and devices” (Khronos Group, 2013). Falanx joined Khronos at an early stage of the group’s development, and obtained a strong voice in the work of deciding which features that were to be integrated into the standard. Falanx, like Nordic and Chipcon, credits their early standardization work with a strong effect with regards to promoting the company among global players.

4.9 Buy-outs and new opportunities (2005–2009)

For some time, Chipcon had been preparing to conduct an IPO, with a target date in May 2005, but the plans were pushed back due to obstacles in the integration process with Figure 8 Wireless. There were some challenges in establishing the proper work environment, and the American company was operating with losses, burdening Chipcon's own financial situation.

It was in the midst of this process, in the summer of 2005, that a major American semiconductor company, Texas Instruments (TI), approached Chipcon about a potential buy-out. Talks were initiated, and in December 2005 a deal was signed in which TI would buy Chipcon for 200 million USD in cash. Chipcon would continue its operations in its offices in Oslo as a subsidiary and would be in charge of TI's efforts to develop low-power radio chips. This also meant that some of TI's employees working in San Diego would start reporting to Chipcon (or Texas Instrument Norway, as it was to be called) as part of the same business unit.

The sales sum was considered very high, supporting Chipcon's claim of being a semiconductor player with bright prospects. The three founders had, at the point of selling, almost 37% ownership amongst themselves, and most of Chipcon's 110 employees also owned shares. Additionally, Alf-Egil Bogen and Vegard Wollan of Atmel had considerable positions. All three of the founders would continue in the company, with Geir Førre leading the integration work, as CEO of TI Norway. He talks about his motivation for selling:

> We sold because of the immense interest [from TI] and because there was so much money involved. But personally I had very mixed feelings about selling because we had big dreams and big ambitions, and we had only come part of the way. But of course, I found it very exciting. We would get financial strength that would make a big difference. I went from having normal wage income to being very independent financially.

Chipcon would get access to one of the leading sales and marketing networks in the industry. In addition, TI owned state-of-the-art manufacturing fabs, and this enabled Chipcon to have some influence over production processes. As a fabless design company, with supplier relations to Taiwanese megafabs, such influence had been impossible.

TI's own motivation for making the acquisition was, for one thing, a perceived complementarity in product portfolio. Their own products within radio communication were underperforming technologically, and they had great difficulties competing with Chipcon and other providers. On top of that, TI had the impression that their customers more frequently asked for radio solutions integrated in semiconductor offerings: Gregg Lowe, head of analog products in TI, commented that it was "extremely important to offer robust and reliable radio solutions" (Halvorsen, 2006, [translation ours]), and his company found a good match in the capabilities of Chipcon.

TI Norway experienced a high degree of autonomy on the inside of the large corporation. TI had been successful in operating decentralized historically, and so they enabled TI Norway to continue making their own strategic decisions regarding products and R&D. Still, they encouraged employees across departments to interact, both informally, and more formally by having international rotation programs for workers. TI Norway occasionally had technology collaboration with other department within TI, and they soon experienced that the bar was low for contacting colleagues for advice. Karl Torvmark talks about such knowledge exchanges:

> There is internal access that allows you to see IP belonging to other departments. It may not always be possible to use such things, but it's also important just to have discussion partners. That was more difficult as a small company. Then it was mostly your competitors who had similar skills, and obviously you couldn't talk openly with them. So here you have a much broader - if you are an IC designer and you're struggling to overcome a problem, then there are others in your company that it is possible to talk to. And TI is very good at encouraging people to help each other. It's not so much centralized control, but it is indeed a culture for approaching another group to ask about things and get help there, and there is a lot of help to get that way. We try as much as possible to work with others. For example, there are people who are experts on voltage regulators, who spend their lives working with that, and if we have problems with such a circuit, intending to include it in one of our products, then it's possible to call them and hear how they have done it and stuff like that, and that's quite common.

TI thus spotted a market trend, that of short distance radio communication on chips, and made a buy-out to acquire relevant knowledge to continue cultivating it in-house. In a similar fashion, major semiconductor players started acknowledging the trends for enhanced graphics on mobile devices, and a period of consolidation was brewing. The success of Nokia N95, a dedicated multimedia phone, was a strong sign from the market place indicating preparedness for such a shift.

Falanx understood that it was important to get a partner in order to prepare for increased commoditization in the GPU market. The huge volumes that were needed to compete against established players required financial strength and sales capabilities. In such a context Falanx started talking to ARM, a British semiconductor company and the leading provider of CPUs for mobile devices. Up until then, ARM had been partnering with Imaginative Technologies, one of Falanx' fiercest competitors, but they were scanning the market for other partnering alternatives.

It was soon understood that ARM was indeed looking for an acquisition prospect. Falanx then reasoned that if ARM decided to buy one of their competitors, then that would give rise to a very difficult market situation. As a back-up plan, the founders of Falanx started looking for alternative strategies for their business operations. An idea was in fact developed, in which Falanx could bypass the device manufacturer link of the value chain and approach end customers directly. The product would be a microprocessor, built into a non-volatile memory card that could take control over any device screen. The four Falanx founders filed a patent for such an idea in late 2005.

But then talks between ARM and Falanx won through, and ARM decided to buy Falanx, having been satisfied with their technology due diligence of the young company. The deal was closed in May 2006 with ARM paying an undisclosed amount, said to be just short of 30 million USD. At this point, the founders and employee owned about 30% of the company, with venture capitalist owning the rest.

ARM would bring to the table strong expertise on the market for mobile devices, built through their own CPU operations. ARM had experience in integrating acquired companies, having gone through several acquisitions of IP-businesses historically. ARM Norway, as the department was to be called, would still be working from Trondheim, and the four founders remained in influential positions, even though an experienced ARM executive would relocate to Norway to lead the office. ARM also intended for the department to grow significantly, and the number of people working at ARM Norway grew from 21 at the time of the buy-out, to more than 50 in the course of a few years. Borgar Ljosland remembers:

> We kept the team structure as it had been, and so we had a company that looked a lot like Falanx in which ARM invested. We hired a lot of new employees and a lot of things that had been a problem earlier were resolved. Now it wasn't money that was the problem anymore, now it was to create business. There was a lot of turbulence in the midst of it, but, even though I don't have a lot of experience from other acquisitions, I believe ARM handled it very well, and that we as entrepreneurs handled it well too, because we got a lot of people to join us [through the transition] into ARM.

ARM was given the choice to include the newly developed patent in the acquisition, but decided not to, because the manufacturing of chips and devices was not their prime business. Instead an agreement was signed between the two parties in which the patent was to be spun off and built into a new company. This gave birth to FXI Technologies, whose first offices would be in Fremont, California. The ownership structure from Falanx was copied into the new company, but the founders had to commit to never start working for the company at any point of time. Trond Sæther would be on the board; the same would some of the investors of Falanx. The new company continued developing the product idea, but without any involvement from Norwegians in the daily operations.

The following year, 2007, Nordic saw further refinement in their operations, continuing the strategic transition to strengthen the focus on standard components. In March, it was announced that they would sell the Data Converter business unit to Chipidea, a Portuguese analog semiconductor design company, for 6 million USD. By now, the RF operations were by far the largest business unit, contributing more than 84%, against ASIC operations and data converter licensing contributing 8% each. Even though data converters had been an even stronger competence area during the mid-1990s, the IP business model had proved harder to scale. CEO Larsen said through an official statement that with the announcement, "Nordic is completing its transition from being a provider of design services and IP, to now, a leading European fabless semiconductor supplier of standard RF components" (Businesswire, 2007).

The unit would be renamed Chipidea Norway, and the plan was to continue operations from Trondheim, with eleven engineers joining the transition from Nordic. Øystein Moldsvor, R&D Director for the Data Converter unit since 2000, would be CEO. The acquisition didn't run smoothly, and by the end of the first year, the number of employees had been reduced to three. Moldsvor believes that the failure of the integration work stems from the fact that Chipidea themselves were an acquisition target at the point of takeover: MIPS Technologies, an American fabless semiconductor company, had initiated talks with Chipidea some time before, and Chipidea might have prioritized being perceived as an attractive target instead of ensuring a successful transition for the Norwegian engineers.

Chipidea Norway was closed down after a few years after a flight of engineers, but the data converter products that had been developed within Nordic, would live on: First within Chipidea, then within MIPS Technologies' analog department, after a successful acquisition completed in August of 2007. Two years later this analog business group was acquired by Synopsys, an American electronic design automation company.

About half of the data converter engineers began in engineering firms in the Trondheim region, including Q-Free, a provider of technology for electronic toll collection, and Atmel Norway. The other half, including Øystein Moldsvor, found their way to a new start-up, to be known as Arctic Silicon Devices (ASD). In fact, ASD was established in May 2007, only a month after the Chipidea acquisition was made public, but it didn't become operational until September 1st that same year. The three founders of the new start-up all had background from NTNU and Nordic: Øystein Moldsvor himself took the position as CTO. Olav Lewis Lindquist had been the first director of the Nordic data convertor unit, but had been working in Fairchild Semiconductors in the US since the beginning of the 2000s. John Raaum, ASD's first CEO, had been employed in the ASIC-department of Nordic, and then in Q-Free.

ASD would make data converters, and targeted the market for mobile ultrasound scanners for medical purposes – an industry growing by 40% annually. The company would, through collaborative research initiatives, benefit from the strong expertise that existed on medical ultrasound in the Trondheim area, especially in the research environment at the city hospital, St. Olav's, and at SINTEF's Medical Technology department.

In fact, Øystein Moldsvor's master's thesis at NTNU had been in the cross-section between medical technology and data converters. The thesis, supervised by Trond Sæther, looked into the possibility of moving the data converter closer to the actual sensor, with the result of decreasing data losses that were due to analog disturbances.

His participatory role in the build-up of data converter expertise in Nordic also influenced his entrepreneurial motivation. In Moldsvor's own words:

> Personally I have seen the value of the competence [data converters for medical ultrasound sensors] that we had built in the middle of the 1990s (…) If nobody would continue working within this area, this competence would crumble and eventually disappear from the country. So, I had a strong desire to continue on the foundation we had laid – continue this development – this was the starting point for me to found Arctic Silicon Devices

Within a year, Arctic Silicon Devices, counting thirteen employees, had developed a product prototype, and they had raised the necessary capital to fund international marketing. The first product, Snowflake, was launched in August of 2008, and was characterized by differentiators typical for the Norwegian semiconductor players: It used only one fourth as much power as its competitors, and was in the forefront on performance.

In 2010, ASD started discussions with Hittite Microwave Corporation, an American semiconductor firm specialized in integrated RF-circuits with micro and millimeter wave applications. Hittite was looking into the possibility of integrating ASD's knowledge into their own value chain, and the discussions came to a successful conclusion in January 2011, through an agreement for buying ASD for 12 million USD. Hittite Microwave Norway was to reside in ASD's offices, and the firm grew from thirteen to eighteen employees during the first years of operations.

2007 saw the birth of another industry start-up, this time from the Chipcon environment. Geir Førre, the Chipcon co-founder and CEO, was eager to start something new, having worked within the structural rigidness of a major corporation for 18 months. In Førre's own words:

> After about one year [within TI], I realized that I had become an entrepreneur, because working within a large company, with all the constraints that it entails, felt very strange. And I started feeling a desire to begin all over again. Or, not really a desire, but rather a thought. That the first 10 years of Chipcon was tough and challenging, but very fun, and that the only way to imagine that the next ten years would be as much fun would be to roll up my sleeves yet again.

Initially intending to try establishing something within another technology segment, Førre came to the conclusion that he would rather "keep being an A-player in the semiconductor industry than become a B-player in something else". His contract with TI prevented him from starting something that would compete directly with their RF-solutions, and so instead he decided on microcontrollers. Before the acquisition, the Chipcon management had in fact thought about expanding into microcontrollers, but the idea was dropped dead when TI approached them, because TI already had operations within that segment.

Førre brought with him Øyvind Janbu, one of the first Chipcon employees, as CTO, in addition to three engineers with plenty of semiconductor experience. Capital was secured to a large extent through the entrepreneurs' proceeds from TI's acquisition, in addition to support from Innovation Norway. The company, named Energy Micro, was fully operational on January 1st 2008, and their ambitious goals resembled those from the Chipcon era: They were aiming for a 1% market share in the global microcontroller market within 10 years.

The start-up would cause some disruption within the Norwegian microelectronics design industry, as Energy Micro recruited from many of the incumbents, including Atmel Norway, Nordic and TI Norway. Recruiting from TI Norway was particularly controversial: Due to non-solicitation clauses in Førre's TI contract, he had to be careful in recruiting people from his old company, and, in explicit terms, any kind of active recruitment was forbidden to him. TI would eventually take Førre to court on these grounds, claiming that he had indeed been recruiting actively, in several cases. They also claimed that the contract forbade him to do any kind of recruitment of TI employees; an interpretation that Førre didn't agree with. The court trial that followed was an unusual one in Norway, and it sparked some public interest. Eventually, TI would lose the lawsuit, but the Oslo City Court was "under considerable doubt" (Halvorsen, 2007, [translation ours]). Førre himself admitted to having crossed the line and that he "had a bad conscious" in one specific case: In the one where he approached Øyvind Birkenes, indeed for recruitment purposes. Birkenes would stay behind in TI Norway, ultimately rising to become General Manager of Low Power RF, leading the Norwegian department.

Energy Micro planned to develop 32-bit microcontrollers, whose prime characteristic would be their ultra-low power consumption. The first generation was named EFM32 Gecko, with EFM being an acronym for Energy Friendly Microcontroller, and the Gecko name taking inspiration from the reptile whose energy consumption is only ten percent that of a similar sized mammal. The EFM32 was based on an ARM processing core, the ARM Cortex-M3, through licensing agreements. The core allowed Energy Micro to perform architectural level optimization and extensions, and it had features that made it well suited for low-power usages. In the words of the company's EMEA sales manager Ian Fletcher, Energy Micro was "the first company that actually releases the Cortex' low power potential" (Energy Micro, 2009), and soon other companies would follow the shift. In fact, Atmel would also include ARM-based microcontrollers in their own product portfolio, from 2009 onwards. Note that Energy Micro now was a competitor to Atmel in many markets.

The product was launched in the US in October 2009, under the slogan "The world's most energy friendly microcontroller". The product had exceeded design specifications, and could extend battery time by a factor of 4 in comparison to similar products. By now, Energy Micro had sales offices in London, Detroit and China, in addition to distributor agreements in the US, Taiwan, Korea, Israel, China and most of the countries in Europe. The products were manufactured in Taiwan. Førre's new endeavor was positioned for growth.

The last two Chipcon co-founders would also leave TI Norway about the same time as Førre did, both of them using the proceeds of the acquisition to invest in new companies. Sverre Dale Moen would eventually become the CEO in a company he helped fund, called New Index. The product idea came from a professor at NTNU about a wireless electronic pen that could make any wall into an interactive whiteboard through connection with a projector. In 2011 the company was sold to Seiko Epson, the Japanese provider of printers and visual products, for 130 million NOK. After the acquisition, Moen would continue as head of product development in Norway. Svein Anders Tunheim worked as an angel investor, investing in several companies in combination with taking positions on the companies' boards. He also invested in Energy Micro.

Much in the same way as the Chipcon-founders, Borgar Ljosland, Falanx co-founder and CEO, grew impatient within ARM. He was offered other opportunities within the corporation, but that would have required him to move abroad, and that didn't resonate with him for personal reasons. In 2009 he decided to leave ARM, and to take a long-deserved vacation.

At this point, FXI Technologies was operating without any influence from the original Falanx team. The news of Ljosland's exit from ARM soon reached the venture capitalists of FXI, which mostly were acquaintances of Ljosland from the Falanx days. They offered to pay his vacation if he would go visit FXI Technologies in California, and evaluate their current standing.

Ljosland accepted the offer, and discovered that the company hadn't advanced much; it had indeed underperformed, in Ljosland's words, given the potential of the patent and product idea. The outcome of this affair was that Ljosland was instated as CEO of FXI Technologies, that the company was relocated to Trondheim, and that the business plans were revised. Ljosland comments on the change in career plans:

> I had by no means decided to go to FXI, but when I came back [from California] I thought: Well, I have invested in it and I have my name on the original patent, and I still believe in the concept. So I was a little annoyed that it hadn't turned out better. So I decided to join the company to have a look, and then one thing led to another. A few months later, I was CEO.

Ljosland entered the company in January 2010, and under his lead the company would change its product idea from a microprocessor integrable to non-volatile memory cards, to be a USB device with HDMI output. In Ljosland's own words: "We've turned things upside down, eliminating the screen and delivering the power of a PC and the web to any screen."

ARM's reaction to Ljosland's decision was one of approval. The only concern they had was with regards to the chance of Ljosland recruiting key personnel from ARM Norway, but Ljosland agreed through contracts to refrain from doing that. Maintenance of important supplier relations to ARM, through the licensing of both CPUs and GPUs was important to FXI, and Ljosland would remain close to the ARM office in Norway, referring to them as "his family". Indeed, Ljosland's asked his ARM superior, VP Lance Gregory Howarth, who was also a board member of ARM Norway, if he would want to step in as a board member of FXI, which he did in the end of 2010.

The continuously evolving environment of the hi-tech industry also provided new product opportunities for Atmel. With Apple releasing their iPhone in 2007, disrupting the cell phone market, other consumer electronics producers were seeking to position themselves in the smartphone segment, and to start offering similar solutions. One of several functionalities that were key in order to offer such smartphones was high-resolution touchscreens, allowing users to navigate the devices using their fingers.

Atmel had supplier relations with many of the companies that started developing their own smartphones, and it was understood that Atmel in fact had much of the knowledge that was necessary in providing a competitive touch-solution. Jo Uthus describes how Atmel actually ended up entering the new product realm:

> We had very good relations to several mobile manufacturers, and when Apple launched the iPhone it obviously created enormous expectations in the market, among consumers as well, about when an iPhone clone would be released from, say, Nokia, or Motorola. I think Motorola was the first, and in that phone we had an altogether standard microcontroller that served as touchscreen controller. It was certainly not the most effective solution, and it was not on par with the iPhone, but it was the first solution. Then we went some rounds with some key customers during which we understood that they were looking for solutions for touchscreens. And so it was decided, in a relatively record time, to expedite the entire process.

Atmel dedicated large parts of their staff in Norway to start developing a touchscreen solution, as much as one third, and went to work in mid 2008. They felt safe that they had the expertise that was necessary in order to develop the semiconductor aspects of the solution. In order to acquire knowledge on touch functionality, they decided to buy a British company, Quantum Research Group, with which they already had partnership activities. Atmel paid 88 million USD for the privately held company. Quantum Research Group was a leading developer of capacitive touch solutions for user interfaces in a wide range of electronics products: Capacitive touch, also known as capacitive sensing, being a solution that takes human body capacitance as input. Quantum Research Group would keep working out of its current offices, but would now report to Atmel's microcontroller business unit in Trondheim.

The acquisition went well, and Atmel was able to release its touch solution, named maXTouch, in May 2009. The development phase had gone on for about a year, and several key customers had been heavily involved in the product definition. The release was a huge success, with functionality that outcompeted all the other solutions on the market, including Apple's proprietary ones. In the words of Harald Philipp, CTO of Touch Technology in Atmel and founder of Quantum Research Group:

> Without a doubt maXTouch is the most advanced capacitive touch chip on the planet. For the first time incorporated into one piece of silicon are all the advances that we've made in the last 13 years, including cost reduction, reduction in the number of external components, high node count, noise filtering, advanced signal processing techniques, gesture recognition. A number of things that have never been seen before in a single device (Atmel TechTalk, 2009)

The power consumption was very low, almost 90% lower than some competitors. In addition, it had unlimited touch, meaning that it could register any number of touches on the screen at the same time, and it was very easy to integrate into any type of device. More than 30 cell phone models would chose maXTouch, including models from Samsung Electronics, Motorola, HTC and Nokia. In early 2011, 8 out of the top 10 smartphones as named by PC World Magazine had maXTouch inside (Gulliksen, 2011). The cell phone market responded reassuringly, and the iPhone all of a sudden had several considerable competitors, laying the foundation for a market situation that would be hugely competitive for years to come. The revenue followed, with the maXTouch product alone selling for more than 100 million USD in its first year, entering its second year with almost 100% growth year-over-year. The Atmel CEO, Steven Laub, named the maXTouch "our most important product" (Tønset, 2010, [translation ours]) and backed his assertion by locating a board meeting in Trondheim, the first time it had ever been outside of the US.

4.10 Positioned for further growth in international markets (2009–today)

The last decade has been one of growth for the five core companies in this study: Energy Micro, ARM Norway, TI Norway, Atmel Norway and Nordic. In 2011, the domestic companies reported revenues of approximately 250 million USD (Proff Forvalt, 2013). These numbers are highly distorted though, by the foreign ownership structure of some of the Norwegian actors: Generally, the MNCs report figures to Norwegian authorities that just about cover the subsidiaries' labor costs and other operational expenses. Sales figures that stems from Norwegian design activity are reported to the country of the corporate center. 55% of total industry revenues is in fact Nordic's contribution alone, but Nordic only employed about 25 % of the industry total (and Nordic's revenue per employee is not three and a half times the average of the rest). A better picture of the activity in the domestic industry, and its growth, might be the number of employees, which is showed in Figure 5. In addition to this, note that some of the companies administer offices abroad.

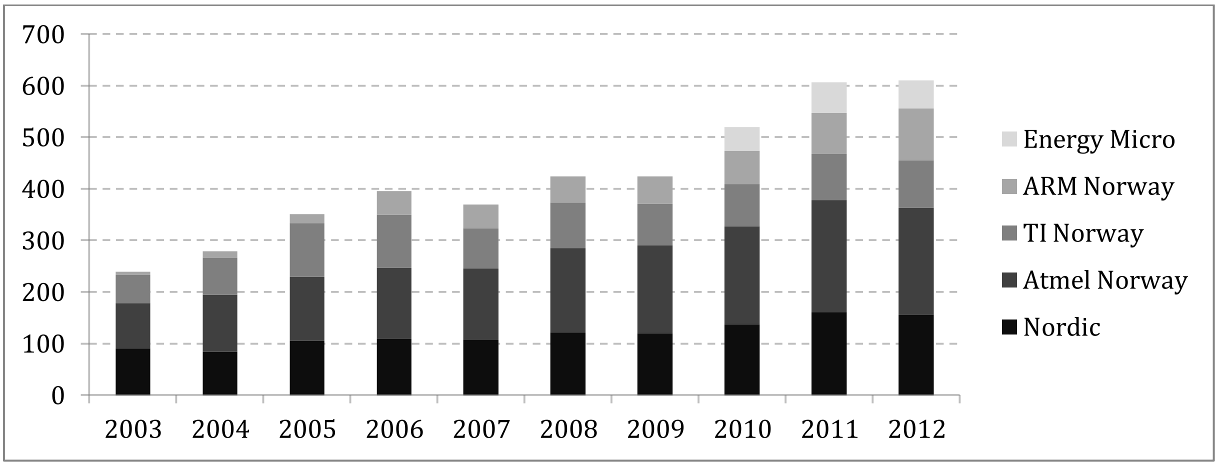

Figure 5: Number of employees in Norway in total per company. Source: Proff Forvalt (2013)

The actors have positioned themselves to profit off of growing and emerging technology trends. One such trend is typically referred to as the Internet of Things; the idea that more and more devices that have been off-line traditionally will be connected to the Internet and communicate with each other. Examples of such devices, or Things, and their new functionality could be light bulbs controlled by smartphones or shoes that register physical activity. In these exemplary devices you would indeed find radio communication functions, and possibly a microcontroller. ABI Research anticipates that more than 30 billion devices will be connected to the Internet in 2020 (ABI Research, 2013).

The focus of several of the companies has been to anticipate these trends in the consumer end-market, instead of planning their product development projects primarily on the trajectory of technology advances. Trond Sæther indeed refers to his company, Nordic, in the 2010s, as “a product firm, not a microelectronics firm”, even though their products are based on microelectronics as a “crucial technology”. The firms are often present on major trade fairs for consumer electronics, including CES, Embedded World and GSMA Mobile World Congress to showcase their products, and promote their solutions.

In 2010, Bluetooth Low Energy merged into the main Bluetooth Standard, during the event of launching the Bluetooth Core Specification v.4.0. The merger was a hallmark event for BLE. The following year, Bluetooth Low Energy was rebranded as Bluetooth SMART. Nordic’s commitment to the Bluetooth standard, and the low power functionality in particular, was acknowledged by an invitation to join the Bluetooth SIG Board of Directors in June 2011. Ericsson, Intel, Lenovo, Microsoft, Motorola, Nokia and Toshiba held the other board positions. Apple, much due to their Bluetooth-compatible iPhone, was asked to join the board alongside Nordic. Nordic would be represented through Svein-Egil Nielsen, Director of Emerging Technologies and Strategic Partnerships. The following year Nielsen stepped up to become Chairman of the Board, a “proud moment” for both him and Nordic. Nielsen used the press release about the appointment to comment on the potential of the Bluetooth standard:

> Bluetooth wireless technology is now positioned to become possibly the most ubiquitous wireless technology in history and a genuine vehicle for technological innovation across all product categories and classes (Nordic Semiconductor, 2012).

Nordic experienced significant growth also for its proprietary solutions, and had a strong position within customer segments including PC peripherals, gaming, and sports and fitness. The first Bluetooth-ready chip, µBlue, was launched in 2009. Standard components stood out as the remaining, championed business unit, with ASIC operations being phased out in 2013. These strategic shifts of product focus were supported by a continued refinement of their fabless model, or as CEO Svenn-Tore Larsen says:

> We outsource everything that can be outsourced, and focus on those things that we are good at. Which is to design the components. We use the leading suppliers in every stage of the process (Lyse, 2011, [translation ours])

TI Norway kept being in the forefront of the trends within low-energy radio themselves, and continued to hold positions within both ZigBee and Bluetooth SMART. The Low Power Radio department would keep expanding, both in Oslo and in other parts of the world. In 2007, TI also bought Integrated Circuit Designs, Inc., a small design company located in Baltimore, US, that was to report to Oslo. Karl Torvmark comments on the purchase:

> The motivation behind the acquisition was to acquire analog expertise. We were always a bit short on analog IC designers, so when the opportunity presents itself then it is very attractive to buy a company if you get it.

TI's chips would be integrated into products ranging from SmartGrid meters, for which it was a huge demand within the US market, to electronic price tags. Volumes and profits increased year over year, and the 2005 acquisition was largely considered a beneficial move for both parties.

The experienced management team in Energy Micro would take the company from a phase of product development to a phase of international marketing, and ensured a visible profile on a number of international electronics fairs. They secured contracts rapidly, and their microcontroller was soon found in customer segments such as health devices, metering and phone accessories.

In 2010, they decided to expand their portfolio by including RF-products. Such a move would make them the first one-stop provider of both low power microcontrollers and low power radio technology. Geir Førre comments on the decision to enter into a market that he knew well from his days in Chipcon:

> The past catches up with you. Together we had had some new ideas about how we could make better radios, with even lower energy consumption. When you make microcontrollers they are very often used in a battery driven system, and in order to make a battery driven system intelligent, it must communicate with other systems. Then

> radio technology is a natural extension. So it is closely connected. This was probably also the reason why the idea of making low-energy microcontrollers got to us in the first place - because of Chipcon's business in making radios.

Energy Micro had a strong focus on recruiting the brightest graduates straight out of their studies at NTNU. Every year they recruited as much as 50 summer interns to work on projects that were too resource demanding for the ordinary staff to pursue. In particular, engineers within hardware and analog chip design were satisfactorily supplied from Norwegian universities.

Recruiting skilled software engineers, on the other hand, was more problematic, also because Energy Micro didn't enjoy as strong a brand name among those students as they did among students in hardware study programs. As a result, the Energy Micro management team decided to do a greenfield investment in Krakow, Poland: In 2012 they recruited a country manager and started building a team of proficient computer programmers from scratch. Geir Førre talks about the rationale for choosing Krakow as their location:

> Given that we have our headquarters in the world's most expensive country, we felt that when we were going abroad for access to skilled labor, (…) we had to establish ourselves in a country where the cost structure is low, and where knowledge and skills are equally high. Eastern Europe is a good choice in general because there are a lot of talented people there, especially within software. Wage levels, and wage level development are much lower in Eastern Europe than in for example China or India. And loyalty is much higher, in addition to a much shorter geographical distance. So we chose a place in Eastern Europe and we chose a place that is a direct destination by plane from Oslo, a city that has good universities, and preferably a country within the EU, where there is less corruption. And then we ended up with Krakow.

The Krakow office had recruited six people by 2013, and was still in a process of expansion. Energy Micro would initiate collaborative activities with Krakow's AGH University of Science and Technology, the largest technical university in Poland, in order to provide students with the skills that are necessary to work in the semiconductor industry.

In February 2013 it was announced that Alf-Egil Bogen, the co-founder of Atmel Norway, would leave his position as CMO in Atmel Corporation to join Energy Micro, where he would assume the same position. Bogen had been living in San José for four years, and looked forward to moving back to Norway. In the press release following his transition Bogen stated:

> I have a strong passion for microcontrollers and radios. After helping to make AVR a very successful business for Atmel I wanted to work more with the ARM cores, which are the industry standard for 32-bit embedded microcontrollers. As an engineer myself I also want to do things that support other engineers to help them be successful. With Energy Micro's extreme low power EFM32 Cortex-M devices and forthcoming ARM radio

> transceivers I saw an opportunity to use all my experience to ensure the company becomes truly customer oriented in providing the products, tools, training and support that developers both need and deserve (Energy Micro, 2013a).

Bogen's emphasis on the ARM cores reflected Energy Micro's focus on working with ARM to achieve their product goals. In April 2013, ARM announced that they had chosen Energy Micro as a partner in a university education program that "encourages the use of ARM processors in electronic engineering and related university courses" (Energy Micro, 2013b). As a partner, Energy Micro would provide students with teaching materials and development tools. The move recognized Energy Micro's commitment to the ARM cores.

As for Atmel, their immense success with the first generation maXTouch prompted other suppliers to enter the market, and the competitive situation became fierce. They continued to supply to cell phone makers on project-based contracts, in addition to expanding into other customer segments in which touch solution became popular. Atmel Norway's microcontroller operations now constituted almost two thirds of total revenues within the corporation: Atmel produced 35 chips every second in 2012, making Atmel the third largest producer of microcontrollers in the world, behind Renesas Electronics and Freescale Semiconductor.

ARM Norway too continued their international success. Their new Mali-400 series was found in several of the most advanced smartphones on the market, including the Samsung Galaxy SII. The workforce stationed in Trondheim had expanded fourfold since the Falanx' days, primarily by recruiting software engineers. The department was soon the fourth largest in the corporation, with branches to Britain, Sweden, China and the US.

The disturbances caused in the labor market after the start-up of Energy Micro calmed, and the companies would go back to a stable situation of low turnover and low inter-firm mobility. As of 2013, the total number of employees with experience from one or more of the other companies is still highly limited, as displayed in Figure 6. As anticipated, the younger firms, ARM Norway and Energy Micro, have recruited some from the older firms. There hasn't been reported any incidences of employees in Energy Micro joining other industry firms.

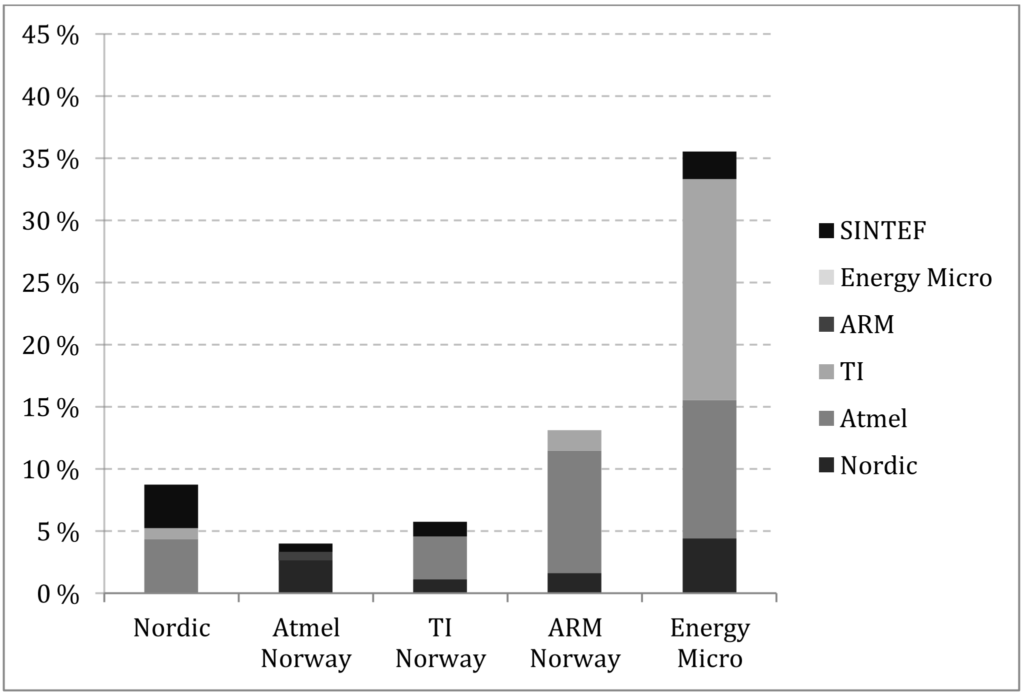

Figure 6: Proportion of current employees with experience from one or more of the other companies. Source: LinkedIn (2013)

The industry participants had reacted similarly to the recruitment difficulties that started in the early 2000s, when the absolute number of graduates was problematically low. Indeed, two remedies had been followed: One was to expand by establishing offices in other countries, deciding on a strategic location as according to the accessibility of skilled workers. Energy Micro had done it in Poland in 2012, and Atmel Norway had done it in China, the Philippines, India and Malaysia in the period between 2007 and 2009.

The other method was to recruit experienced foreigners, and offer them to relocate to Norway. Among the last twenty software engineers hired in ARM Norway, as of December 2011, only three were Norwegians. In total, ARM Norway employs engineers from sixteen different nationalities. Similar patterns can be found in the other companies: Energy Micro, for instance, employs people of thirteen nationalities, across four continents, in their Oslo offices. Atmel Norway similarly has a presence of nineteen nationalities, up from four in 2000.

By recruiting people from other sources than NTNU, the companies experienced an inflow of new impulses and working methods. Trond Sæther comments on the shift towards foreign sources for new talents, as seen from his perspective in Nordic:

> What we have experienced is that we are now so internationally recognized that it offers very few problems getting good expertise to Trondheim; so, at the same time as we are getting more known abroad, it has gotten easier to attract foreign expertise. That's quite different from how it was ten years ago, for example, when we were much more dependent on getting people locally.

Foreigners have somewhat higher turnover rates, as can be expected, but in general most of them are content about working in Norway, and stay for several years. If particular engineers are deemed valuable, there have even been examples of the Norwegian companies accommodating employees so that they could work from home-based offices, in their country of origin.

Still, it is worth noting that the legacy of the domestic universities, and in particular NTNU/NTH, is highly relevant in the industry, even today. As displayed in Figure 7, more than 40 % of all the employees in the industry have roots back to NTNU (based on the registered institutions on employees' LinkedIn-profiles; due to a large number of people without a registered university background, the number is probably even higher). The second most popular technological institution is Sør-Trøndelag University College (HiST). With a location in downtown Trondheim, HiST has been an especially important source of labor for the Trondheim-based companies. The University of Oslo (UiO), despite their geographical proximity to many of the actors, represents a relatively low proportion of the educated labor force, with less than 5 %, (the same as the two most relevant Swedish universities).

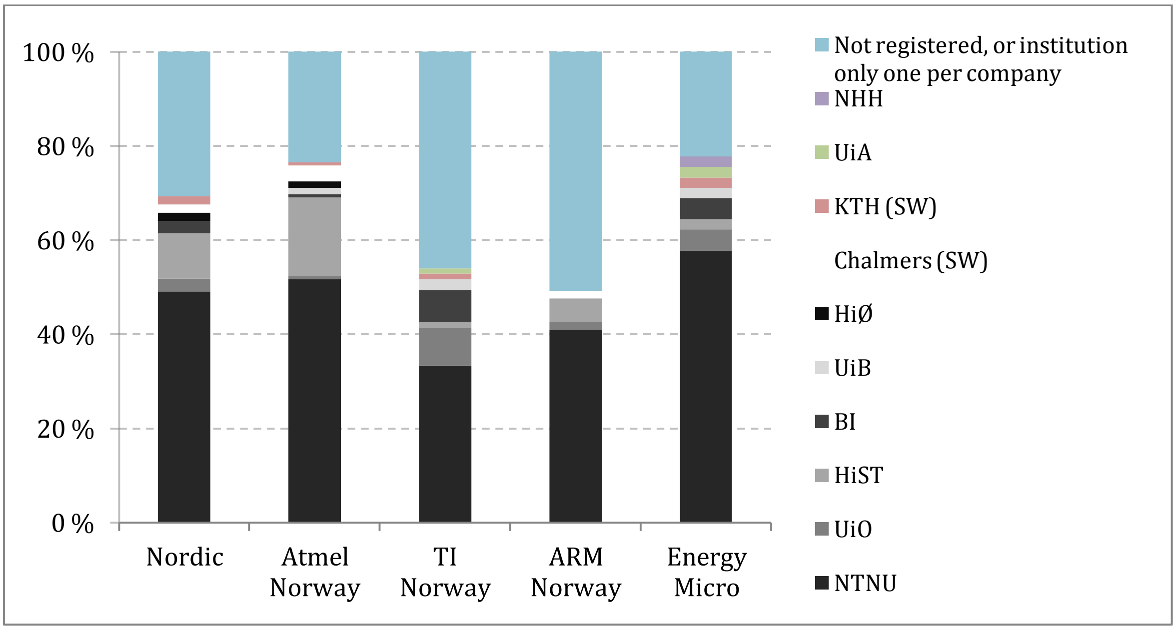

Figure 7: Current employees split by educational institution. Source: LinkedIn (2013)

Part 5: Discussion

We started the thesis by constructing a model for technology diffusion that envisioned two knowledge environments in which an international firm could have a position; the domestic knowledge network, and the international knowledge network. A set of propositions was postulated based on a range of theoretical concepts, with the intention of describing aspects that was necessary for national industry development, and for technology transfers across and within borders.

The chosen case, the Norwegian microelectronics industry, was described through five decades of activities: From Olaf Stavik's pioneering research in the 1960s, through ELAB's research activities in late 1970s, up until today, when there are several domestic companies and domestic subsidiaries that run highly profitable design operations. Throughout this period, the firms have turned their attention from domestic markets, to largely global markets, and they sell products in volumes of millions every year. The investigators were well received when contacting industry actors and many of the key insiders were willing to contribute. There was a particular goodwill with regards to the work of collecting the stories, and writing the full account of how the industry has evolved.

5.1 The domestic knowledge networks

Some highly interesting insights emerge after considering the conditions for knowledge sharing in the domestic market. Indeed, the companies' locations have gotten less important to competitive success as the industry has evolved and grown. We are inclined to argue that our results do not concur with the strong theoretical emphasis on beneficial aspects of regional agglomeration of firms. This section will elaborate on our critique of the cluster mindset by discussing the elements that we expected to identify in the domestic knowledge networks. The structure follows the theoretically derived proposition.

The first set of propositions was derived from Porter's (1990) diamond model, and was used to investigate three conditions that were thought necessary for a country to foster successful companies in any given industry. The reason for our choice to investigate elements of the diamond model, was the immense interest it enjoys from cluster theorists (e.g. Maskell and Kebir, 2005) and in industrial policy making (e.g. Bahlmann and Huysman, 2008; Glăvan, 2008).

The first of these propositions, Proposition 1a-i) *Domestic supply of labor with relevant education*, found support in the case study, especially in the early stages of the industry development. Clearly, recruitment from the domestic universities (NTNU, formerly NTH, in particular) has been of major importance historically: A majority of the industry labor force got their diplomas from NTNU. We note that the initiation of relevant education programs at NTNU went hand in hand with the escalation of research activities at ELAB.

This was a foresighted and necessary initiative that became essential to commercialize microelectronics knowledge and to support initial growth.

Eventually though, the emphasis on NTNU as the single most important recruitment source declined. The absolute number of graduates wasn't satisfactory to support continued growth, and the companies turned their eyes to foreign sources for new talent, either by recruiting them to the Norwegian offices, or by opening new offices abroad. This also allowed the firms to tap into foreign knowledge bases, and transfer valuable knowledge, embodied in individuals, to the domestic knowledge system, allowing for ideas that differed from those taught in electronics classes at NTNU.

This observation certainly poses challenges to cluster theory's emphasis on domestic education institutions. The technological firms did not refrain from recruiting talent abroad; these patterns weren't even regionally bounded, with recruitment from countries across the globe.

Proposition 1a-ii), *Significant domestic demand conditions*, did also obtain support only in the early stages of the industry development. Initially, strong domestic demand conditions were pivotal in the industry establishment. Large industrial actors had been made aware of the possibilities of ASIC products, and concurred with the ELAB researchers when they anticipated a growing need for Norwegian microelectronics competence. Activities during the first few years were driven primarily by this domestic demand, which allowed for both commercial viability, and for continued knowledge development, often through extensive experimentation.

Subsequently, as the industry actors became engaged in standard components, the dependence on domestic demand declined drastically. Today, most firms experience export ratios above 99%, and domestic deals have no implications for any of the firms' strategic decisions. There has not been an emergence of a domestic buyer-industry that can offload the industry firms of their product offerings. For instance, no large consumer electronics firms have their home base in Norway.

Throughout the story, we did observe fierce competition between several domestic actors. At this point, our observations are in accordance with Porter's (1990) model. Competition was observed between Nordic, Chipcon/TI Norway and Gran-Jansen/BlueChip on RF, and between Atmel Norway and Energy Micro on microcontrollers. In recent years, Energy Micro has also started experimenting with RF-solutions, setting them up as potential competitors of Nordic and TI Norway in some markets. Geir Førre credited the Chipcon/Nordic competitive environment for some of the success that both firms have experienced internationally. Proposition 1a-iii, *Competition between domestic firms*, have support.

Certainly, Porter's diamond model does not explain the industry's success when examining a snapshot of the industry today. Dependence on domestic conditions has declined gradually for all industry firms, even though they have been instrumental in the early stages. The next set of theoretical derivations and propositions investigated the domestic prevalence of specific knowledge exchange mechanisms, and we arrive at similar conclusions here: Today the industry firms operate without being embedded in local knowledge networks.

First we consider Proposition 1b-i, *Local collaborative activities*. Today, such collaborative activities are almost completely absent. Svein-Egil Nielsen of Nordic interestingly observed that there would be no reason to cooperate with Norwegian actors only on account of them being Norwegian. The firms seek collaborative engagements where there are actors with complementary interests and capabilities.

Historically, collaborative activities have also been largely absent, with company insiders suggesting that the competitive situation between industry firms limits the viability of cross-company initiatives. The only large-scale collaboration that we identified was the one between Falanx and Nordic in 2003; a project that actors on both side perceived as beneficial. The companies were not competitors, and personal relations between company insiders had been an important antecedent to the collaboration.

We did identify some communication across actors during the start-up processes. Insiders in the older firms shared experiences about their own establishments with new entrepreneurs, and technological and market aspects were discussed. The Falanx founders, for instance, discussed business model choices with insiders in both Atmel Norway and Nordic. This communication had a more informal character than that of a formalized collaboration. Cluster theorists, including Porter (1998) and Saxenian (1996), have highlighted benefits of informal interaction in cluster environments. Our findings suggest that such communication is especially advantageous to inexperienced entrepreneurs throughout their start-up processes. We also note that such communication bear witness of goodwill among incumbents to industry enlargement.

There is one collaborative activity that is worth noting, and that is the cooperation between commercial actors and NTH, the primary domestic research institution which we initially perceived of as a contextual actor. In addition to being a recruitment source, the close link between the industry firms and the university have supported domestic learning efforts throughout the industry evolvement. The firms have used different arrangements to tap into the resources of the university. One example has been for firms to author and supervise master's theses, with the company insiders describing such efforts as a great way to investigate new areas of research and to discover student potential. Several strategic technologies emanated from master's theses, and this became an arrangement that would characterize the industry throughout its evolution.

As for inter-firm mobility, we note that the overall turnover has been consistently low in all companies, with the exception of some mobility in periods of new industry start-ups. This is a surprising finding, and stands in contrast to the findings in other hi-tech clusters, including the studies of Saxenian (1996) and Fallick et al. (2006) from Silicon Valley, and Power and Lundmark's (2004) study of the Stockholm ICT cluster.

It could be argued that the low mobility is explained by characteristics in the domestic labor market. For example, the Norwegian employees seem to have a strong preference for being stationary: The industry has presence in both Trondheim and Oslo, and there's not much willingness to move between regions. Another element could be the industry norm of not using pay raise as a mean to attract new talent. Norway has high and increasing salary levels, and none of the firms would benefit if they set in motion a spiral of increased salaries amongst themselves. A third element might be the relative strictness of Norwegian labor laws, especially when compared to for instance Silicon Valley. As an example, the termination of employment requires a long notice period (one month by law, often three months by contract).

Even though there is low mobility of workers in the industry as a whole, some rotation of key individuals have been noted. Individuals have moved between university environments and commercial actors (e.g. Einar Aas, Trond Sæther and Oddvar Aaserud), from one start-up endeavor to the next (e.g. Geir Førre and Borgar Ljosland) and between central positions in industry firms (e.g. Alf-Egil Bogen). In addition, individuals have had parallel engagements, either in several firms at once (e.g. Frank Berntsen, CTO in Nordic, and unofficial advisor to Falanx in the early 2000s), or with executive positions in one firm and board position in another (e.g. Trond Sæther, director in Nordic and board member in Falanx, FXI Technologies and Novelda; and Alf-Egil Bogen, director in Atmel Norway and board member in Chipcon and Novelda).

In the end, Proposition 1b-ii), *Intra-industry mobility of workers*, only gets limited support: The overall mobility of workers is low when compared to other national hi-tech industries, but the flow of key individuals has been important in several of the processes that have formed the industry.

Several spin-off processes are distinguishable in the industry case study, so Proposition 1b-iii), *Historic spin-off processes*, finds support in the case evidence: Nordic came from the ELAB research environment, and Atmel Norway had strong roots to Nordic, both product wise and with regards to human capital. The competencies that were to constitute Energy Micro had strong antecedents to Chipcon, and Chipcon itself was a spin-off from SI research activities. FXI Technologies' business model is based upon a patent that was developed inside Falanx. The figure in Appendix F shows these spin-off processes as a system of knowledge transfers, with knowledge diffusion *from* established expert environments, *to* the new firms for cultivation.

The Atmel start-up is an exemplary case of the knowledge spillover theory of entrepreneurship, as outlined by Acs et al. (2009). Nordic's RISC processor, first designed by co-founder Frank Berntsen, was never considered a prospective stand-alone product by the Nordic management. But two young engineers, Alf-Egil Bogen and Vegard Wollan, valued it differently. The mismatch in valuation became an antecedent to the start-up of Atmel Norway, as the two engineers brought the idea to California and managed to convince the Atmel CEO of its commercial potential. In accordance with the "Born Local" model of Acs and Terjesen (2007), Atmel and other spin-offs ended up being situated at the locations where the spillover opportunities had arisen. Increased entrepreneurial activity in regions with specialized firms was also highlighted in Porter's (1998) cluster models.

It is worth commenting that a shared background has not ensured a close connection between the spin-off ventures and the parent companies after the split. We did not identify distinctive patterns in such relations that differed from relations between firms without shared backgrounds.

Proposition 1b-iv), *Presence of relevant research institutions,* is also supported, but the institutions' contributions were most important in the early stages. Certainly, the research institutions were essential in the beginning, by being the first to adopt the new technology, initiate the first learning activities, and also built early domestic demand. The first industry companies stemmed directly from the research institutions. But as the industry progressed to become truly international, the firms started having very limited ties to domestic research institutions, or to any research institutions for that matter. The firms are highly product focused, with limited interest in basic research.

The core observation is that domestic conditions were instrumental in providing a foundation from which commercial activity could emerge and grow in the early stages. As the industry has grown, domestic knowledge networks have gotten less important to all commercial actors, to the point were few of the theoretical concepts from cluster theory in general, and Porter's (1990) diamond model in particular, find support in the evidence. Still, local entrepreneurial activity stands out as a highly significant knowledge spillover mechanism, and the individuals that are part of such processes become important change agents allowing continued industry growth.

5.2 The international knowledge networks

Turning to the international knowledge networks, we observe that such networks have become highly important to industry participants; more than what would be guessed judging by the limited interest they have obtained from international business literature. The firms gradually entered such networks as their focus turned to international markets, and as their export ratios increased, and have been deeply embedded in them ever since. The transition was gradual. The first exporting activities happened in the days of Nordic's ASIC operations, but accelerated largely as the firms decided to develop standard components. Certainly, the gaining of market shares internationally was a highly targeted effort. Selling to companies across the globe was necessary to support growth trajectories.

We derived Proposition 2-i), *Transfer of knowledge through international trading channels*, based on international spillover theory. In accordance with proposed learning effects (e.g. Grossman and Helpman, 1991), we have identified several supplier relations between industry participants and world-leading technology firms, where discussions about the provided solutions have been a way for industry participants to expand their own knowledge bases.

In particular, it appears to be significant learning through the export channel, as suggested by Silva et al. (2012). Such buyer-seller discussions were instrumental, for example, in Atmel Norway's opportunistic decision to start developing a touchscreen-solution. Momentous projects of Nordic's with significant learning outcomes included the development of satellite solutions with European semiconductor actors, and the development of cordless-features in the Logitech mouse. International relations became sources for understanding the market situation and market direction. As firms providing technologically advanced products, it has been instrumental to be at the forefront of what is happening on the global arena.

The FDI channel has also been a way by which the domestic firms acquire new knowledge and technology. Atmel Norway, for instance, acquired capacitive touch knowledge through the acquisition of a British firm, Quantum Research Group. Similarly, foreign firms have been acquired by Texas Instruments to contribute to the knowledge base of the Norwegian subsidiary. The motivation for such acquisitions is indeed largely to acquire new technology, and diffuse it throughout the organization, to enhance product offerings. Accordingly, this knowledge also diffuses across national borders. Some FDI through greenfield investments have been identified: Atmel Norway stands out as the actor that most consistently has established new offices in foreign countries; Energy Micro recently opened its first foreign R&D office, in Poland. The motivation is two folded: Often the primary reason is the push to go abroad due to a difficult recruitment situation in Norway, but there is also an intention of tapping into knowledge that is embodied in foreign labor pools. We will suggest that the FDI done through acquisition is superior to greenfield investments when the intention is to acquire foreign knowledge. Branstetter (2006) found similar results when investigating FDI between Japan and the US.

The import channel is of minor importance for knowledge transfers in the domestic fabless semiconductor firms, because of a relatively low dependence on resource inputs other than human capital. Some purchases of software development tools are necessary, but often these solutions are undifferentiated and provided through pure market transactions. The linkages between the Norwegian companies and the manufacturers of the chips, often situated in Asia, are also purely market based. The megafabs have a specified set of preferences for how the product data should be provided, and seldom do discussions regarding product processes occur.

We did identify international collaborative activities that occurred without vertical linkages. As such, we confirm Proposition 2ii), *International collaborative activities,* even though such activities did not pick up until the actors had established presence in the international market place. Initially collaborative efforts were important in promoting the domestic firms' technology solutions. They often experienced to be noticed due to their technology capabilities. Eventually, collaborations have also helped domestic firms identify and incorporate foreign developed technology, and to push shared interests. Falanx cooperated with game developers because of a common interest in promoting enhanced graphics processors to device manufacturers. The recent announcement regarding Energy Micro's strategic alliance with ARM is a way to prepare a new generation of programmers for the use of their products. The industry firms have been able to cultivate and maneuver in international knowledge networks despite large spatial distances between partners.

We found strong beneficiary effects for firms participating in international standards consortia. These have been settings in which the firms, despite their small sizes, have had substantial impact, and where knowledge exchanges often occur. It must be noted that the participation in consortia, for example in the instances of Chipcon and Nordic, are highly linked to the nature of their focal technology. Wireless communication has been a field that has been drawn towards standards as a natural progression. In effect, it is difficult to generalize the beneficiary effects that the firms have experienced after participating in such collaborations.

As the firms entered global technology markets, the channels through which they adopted technology became channels for knowledge exchanges *from* the firms as well, with the effect of making the Norwegian actors conduits for technology diffusion across national borders. Such global ripple effects of the firms' economic activities must be understood as among their most important contributions in economic development, in the way such development is modeled in endogenous growth theory (e.g. Romer, 1990).

5.3 The model of international technology diffusion

The results are very interesting when we connect our findings on domestic knowledge networks with those on international knowledge networks. The domestic conditions were essential in laying the foundation for a microelectronics industry, but as the industry evolved and grew, the industry participants turned their focus outside of national borders. The participation in international knowledge networks must be understood as a necessity for effective competitiveness in global technology markets. The transition has been a gradual one, with focus turning abroad on expense of domestic embeddedness. Today, the industry participants are "external stars", as defined by Giuliani (2005), and the domestic environment has few points of intersection between industry actors.

Indeed, today, the firms' geographic location is of minor importance. Several interview objects commented that their location hardly affects their operations, and that their current location should be understood as a factor of legacy. This is where the firms have been historically, and now they will remain here largely because their employees are well-established here themselves.

A range of industry case studies have challenged the predominant cluster theories for explaining firm competitiveness, consistent with the findings presented here. Niosi and Zhegu (2005) questioned whether local or global knowledge spillovers were most important in aerospace clusters, and rejected the local knowledge spillover explanation of agglomerations in the aerospace industry. Boschma and Ter Wal (2007) observed that few companies in the Barletta footwear district in Italy was in fact connected to the local knowledge network. Morrison (2008) similarly found that leading firms in the Murge furniture district in Italy were well connected externally, but that linkages to district firms were highly limited.

We differ from those case studies in our historic approach. Looking at the industry historically provides more consolation with cluster theories than a snapshot of the situation in the industry today. The strength of our study lies in the fact that we allowed for the investigation of aspects in the two knowledge networks over time, tracing the industry history from its earliest roots to its current situation. The observation that the structure of the technology diffusion system changes with time requires a rejection of Proposition 4): Which knowledge network that is preferred changes over time, and the international technology diffusion model cannot be considered static. Evidence points to the importance of both international and domestic knowledge networks, but at different points in time.

After the extensive description of the Norwegian microelectronics industry through five decades, we suggest that the industry have gone through four phases with distinctive characteristics. The relative importance of domestic and international networks changes when transitioning between them:

We call the first phase the ***initial phase***, because it concerns the process of adopting a new technology and introducing it to the domestic knowledge system. In the case of the Norwegian microelectronics industry, individuals identified the focal technology through their personal international knowledge channels. As soon as the new knowledge resided in domestic actors, the domestic knowledge networks dominated in the initial phase, with an especially strong emphasis on the pioneering roles of domestic research institutions.

The initial phase was superseded by a ***commercializing phase*** where actors realized economic potential inherent to the acquired technology. When conceiving of the commercializing phase as a general phenomenon we believe that, depending on whether the knowledge has diffused across domestic actors, the technology might be commercialized by the pioneering actor, or by another domestic firm. In the case of the Norwegian semiconductor industry, the first major commercial firm was indeed a spin-off from one of the pioneering actors, ELAB. At this point in time, domestic knowledge networks continued to be of importance: Domestic demand, in particular, was driving this phase.

The national industry emerged as commercialization and knowledge diffusion continued over a prolonged period of time. We refer to this phase as the ***industrialization phase***. Here, the competence in microelectronics that resided in the research environments and in Nordic led to an expansion of both number of industry firms and increased industry profitability from the mid 1990s onwards. The industrialization phase was one of new start-ups, with local spin-off activity as a powerful spillover mechanism. New and old firms experimented with various business models in order to find the most sustainable ones. Entry into international markets was highly tempting from the perspective of business profitability, and the first export activities started taking place. Informal communication and sharing of experiences occurred between industry participants, and we did identify some formal collaboration projects.

The characteristics of this phase are highly interesting, because the phase represents the escalation of industry development. This phase laid the foundation for a continued realization of large economic benefits inherent to the acquired technology.

The last phase we think of as a ***mature phase***. In the Norwegian microelectronics industry, this phase is largely ongoing. At this point we observe an established pattern as to how the industry participants structure their knowledge networks and how their mutual interaction is organized. As the mature phase has evolved, the industry firms have succeeded greatly in their international endeavors, and they have abandoned their local environment, largely to leverage international knowledge networks through increasingly global sales channels. Even dependence on domestic recruitment sources has declined. There are still examples of entrepreneurial activities, but these start-up firms take the form of international new ventures whose resources are dedicated to foreign knowledge activities, rather than domestic ones.

We note that we have observed presence of all the proposed aspects that we derived from theory, but the relative importance of each of them has changed over time. The introduction of phases provides a powerful way for discussing these fundamental transitions. Figure 8 is meant as an illustration where we have combined the four phases with each of the proposed aspects.

5.4 The role of technological gatekeepers

We do not find strong evidence for firms acting as technological gatekeepers, and thus proposition 3) is not supported. We suggest that firms were oriented towards their domestic environment in the early stages of the industry development, then to their international markets in recent years, as external stars (Giuliani and Bell, 2005). This is interesting in light of Giuliani's (2005) emphasis on the technological gatekeepers as a

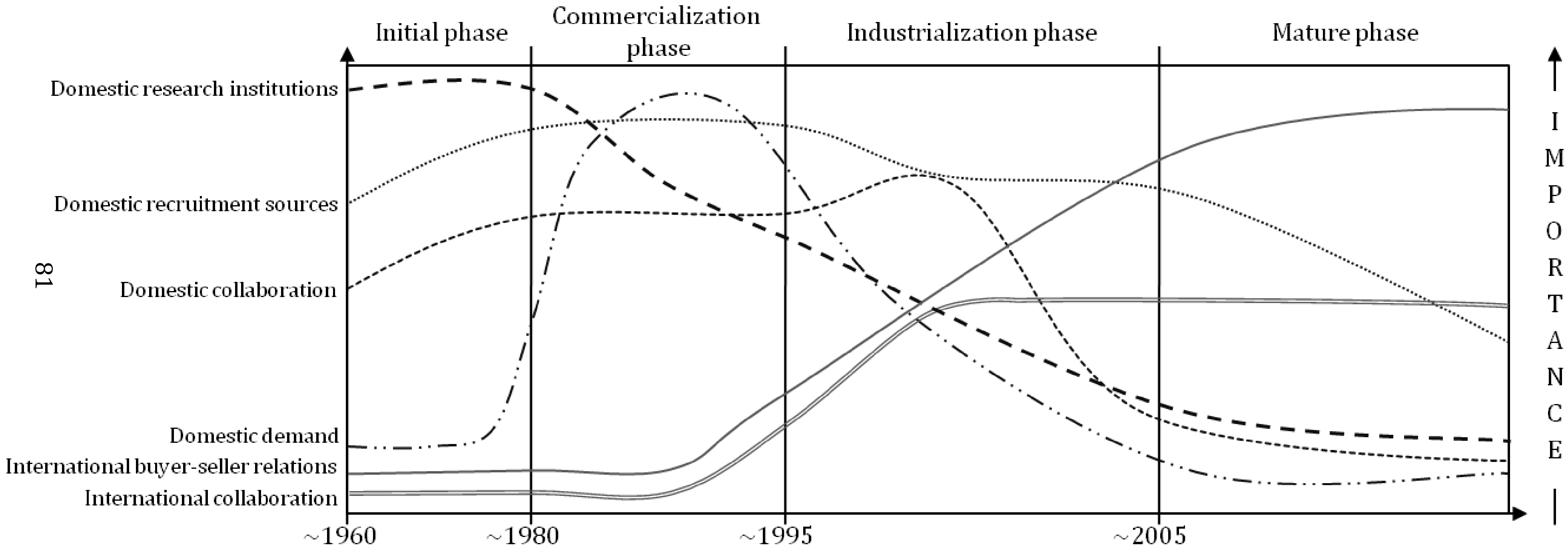

Figure 8: Illustration of the relative importance of domestic and international knowledge networks throughout the four phases

critical actor in the cluster diffusion system, and suggests that their presence is less critical in the development of national industries. This section will discuss the categories of firms as we outlined them in the theoretical introduction and comment on the observed behaviors.

We identified several firms that qualify as International New Ventures as according to Oviatt and McDougall's (1994) definition. Falanx was highly ambitious with regards to the geographic scope of sales activities. Energy Micro established sales presence in regions spanning the globe soon after their start-up. Even Atmel Norway, even though they had financial support through the Atmel Corporation, was soon after inception offering their products to a truly global market. The suggestion that these firms act as technological gatekeepers, does not find supportive evidence though. The INVs are highly focused outside of their national borders, and domestic conditions are largely neglected. Due to their lack of resources, the firms prioritize presence in the markets where they are to sell rather than in domestic environments.

The two primary stages firms in our study, Nordic and Chipcon, establishing a strong domestic presence before turning to international markets, did not act as gatekeepers either. First they were focused inwards, on domestic conditions, with relations to their parent research institutions and dependence on domestic demand. As they prepared for international market entry, the ties with domestic actors were loosened, and new relations were established in their place with international actors.

Similarly, the MNC subsidiaries have been highly focused on international markets. MNC presence was established in a period where domestic knowledge linkages weakened overall. As such, there is not much evidence pointing to actors in the domestic knowledge networks enjoying an inflow of new knowledge through MNC presence. This observation, that MNC subsidiaries never became embedded in domestic knowledge networks, stands in stark contrast to the findings of Birkinshaw and Hood (2000). We thus reject the role of incoming FDI as a channel for international spillovers into the domestic knowledge system. Branstetter (2006) arrived at a similar conclusion when investigating FDI, in the form of acquisitions, of Japanese firms in the US. He argued that this was so because acquisition was used as an FDI mode when the Japanese firms intended to tap into American knowledge.

There is evidence pointing to strong international knowledge linkages internal to the MNCs. Corporate centers encourage knowledge diffusion across subsidiaries. Such a managerial priority is consistent with the findings of Sölvell and Zander (1995), who highlight the beneficial effects of knowledge diffusion in organizational networks. The internal knowledge networks become channels through which knowledge diffuses across the national borders, with the subsidiaries as both absorbers and sources. The mechanisms for knowledge exchanges included communication across departments and internal work rotation programs.

In spite of a lack of evidence for spillovers from inward FDI, we won't make the claim that the acquisitions have been disadvantageous to the domestic industry. Quite the opposite; the targeted firms have experienced significant growth since their respective takeovers, and the evidence points to the role of MNCs providing financial backing and access to global sales networks.

Part 6: Implications

6.1 Academic Implications, and Future Research

We believe that we have contributed to the research literature in three ways.

First, we have derived a model for understanding international technology diffusion, which bridges the research traditions emphasizing localized and distant knowledge systems respectively. The model in its simplest form can be thought of as a framework for understanding how firms acquire external knowledge. We argue that knowledge antecedents can be traced through knowledge interaction linkages that are either domestic or international.

Second, we suggest that international knowledge networks can be as important as domestic knowledge networks. Companies that seek international competitiveness often benefit from being embedded in technology networks abroad, where they can identify and adopt knowledge that allows them to be responsive to the international market place. These observations are particularly interesting as they challenge cluster theorists' emphasis on localized knowledge systems as the defining feature of industrial organization.

Third, we envision industry development as a process that goes through phases; which of the two distinct knowledge networks that is dominant changes as the industry evolves. The evidence points to a relation between an industry's dependence on domestic sales, and the significance of domestic knowledge networks: As soon as firms seek to succeed in international markets, learning focus turns outside of national borders. The findings stand in stark contrast to the key assertion of cluster theorists; that "the enduring competitive advantages in a global economy lie increasingly in local things" (Porter, 1998, p.77).

Future research must be preoccupied with understanding the extent to which the case evidence is generalizable to other industries. The Norwegian microelectronics industry meet the definition of the effective international technology diffusion, derived largely from Porter's (1990) notion of competitive national industries, but it has several particularities that might confound the results. For one, Norway is a small economy, and companies are often compelled to enter foreign markets due to insufficient domestic demand conditions. It could be so that the body of knowledge that resides in the local knowledge systems is insufficient in a similar fashion, pushing firms to seek abroad for responsiveness to technology trends. Industries in larger economies might thus behave differently. Another distinctiveness is that microelectronics is a hi-tech industry, with an immense pace when it comes to technological advancements. Other industries, with less of a need for continuous upgrading of current knowledge bases, might have different patterns than the ones observed.

A natural extension of the model as we have presented it, is to incorporate the research and development activities that the companies conduct internally. This would set up firms as not only diffusers and absorbers of knowledge, but sources of new knowledge as well. The emerging model is a more coherent system of innovation, where both connectedness and internal research capabilities are qualities decisive for competitiveness. If structuring a discussion along these lines, concepts like current technology base and absorptive capacity become important.

The role of key individuals was not included in the theoretical model in explicit terms. The strong evidence for their influence on industry development suggests that future research can benefit from incorporating the individual as a unit of analysis. If international technology diffusion and industry building depend so much on the actions done by a handful of people, then it might be insufficient to analyze systems populated by firms in exchange relationships. Instead, it would be key to understand the inspirational sources and knowledge networks of individual entrepreneurs, the conditions that enable them to pursue their entrepreneurial aspirations, and the motivation that makes them enter world markets.

In addition to theoretical contributions, we have gone to great lengths to chronicle the evolvement of the Norwegian microelectronics industry. This document is an extensive account of the major events of the national industry's 50-year-old history, and we believe that it can serve as a basis for subsequent discussion and analysis. Future research can use the case depiction as a platform to elaborate on specific aspects, such as the international entrepreneurship activities, the relations between the industry and the universities, or the FDI and buy-out processes. Other areas which are interesting from a theoretical point of view, but which are not prioritized in our depiction, includes the financing of the industry development, and the role of governmental agencies.

6.2 Implications for Practitioners

There are two distinct groups of practitioners for whom the results hold implications. We identified these two groups as the business managers and the policy makers already at the outset of the study. At that point, we suggested that the prevalent literature was highly confusing to both groups, through their diverging advices on how to think about local versus distant knowledge relations. We believe that the observations made in this thesis hold implications that clarify some of the confusion.

To business managers we suggest that there are still two modes of networks to consider, but that the appropriateness of either of them differs by the ambitions of the firm, and the state of the industry as a whole. As long as the firm is largely domestically oriented market-wise, there is reason to believe that the advantageous knowledge partners reside in domestic markets, be they domestic customers, research or education institutions, or other industrial actors. As the firm and industry internationalize, the study provides evidence for the significance of international knowledge networks in securing international competitiveness.

For policy makers, we argue that it is necessary to understand the requirements for competiveness of domestic companies before promoting initiatives that focus on one of the knowledge networks over the other. If responsiveness to the international market place and to global technology trends is necessary, then encouragement of local embeddedness could inhibit foreign engagements by forcing limited resources away from where they are most needed. The predominant industrial policy regimes, often based around aspects of Porter's (1990) diamond model, are thus challenged by the findings of this study.

We will emphasize that domestic research institutions and universities have played essential roles in the initial technology adoption, and in continued diffusion and commercialization. As environments with sufficient absorptive capacity to decode and acquire new technologies, they constitute the foundation from which new industries emerge. Understanding the invaluable contributions of these institutions is key, and here governments have significant influence.

The entrepreneurs become the change agents that enable successful commercialization of the knowledge that resides in these institutions. Indeed, the microelectronics industry stands as an exemplary study of entrepreneurial activities driven by ambitious risk-taking individuals. Industrial policy makers can contribute by encouraging and facilitating entrepreneurs in their endeavors; managers in industry incumbents can play an important role by sharing their experiences and providing advices in start-up processes. We hope that our retelling of this Norwegian industrial adventure inspires engineers and others to keep building successful companies and successful industries.

Part 7: Limitations

It could be questioned whether the propositions cover enough theoretical constructs to allow for strong inferences regarding the local versus distant debate. Similarly, as it was commented on in the methodological review, the framing of the propositions could possibly allow for some discretion in the process of analyzing the case data. We will argue that the constructs that we focused on are highly central to the respective research traditions, and we were conscious about formulating the propositions so that they allowed for gross matches or mismatches.

Some cluster theorists have operationalized the cluster concept by stating precise terms for the degree of geographical agglomeration, and the number of relevant firms. According to some of these terms, our case of choice might not be considered a cluster: We investigate less than ten companies, employing less than 1000 people, and they are located in two different Norwegian cities, Oslo and Trondheim. As such, one could question whether our results could be considered critique of the cluster models in general, or only critique of the cluster models as a framework for understanding the competitiveness of national industries (which was indeed Porter's (1990) starting point).

There is also a point to be made about the segment of the industry that was chosen as case. In addition to the firms analyzed, there are a number of other Norwegian firms with microelectronics competencies. A full industry case study could have included those as well, and there is the chance that other patterns would have emerged. A larger number of interviews with insiders in the companies we did choose could have also provided more complete data. There are a few key individuals in the sector development that weren't interviewed, including Alf-Egil Bogen and Vegard Wollan of Atmel Norway. Unsuccessful attempts were done to get in touch with them. In addition, no current employees in ARM Norway were interviewed.

Lastly, more focused operational measures could have communicated the findings better. We decided, as Figure 3 depicts, to identify and depict all the major events and trends over the course of the industry development, even though not all involved traceable knowledge exchanges. As such, the case depiction is extensive, and not all events were interesting for subsequent discussion. The thoroughness can be seen as a way of validating the study's ability to identify those knowledge exchanges that have occurred. In addition, as was discussed in Section 3.4, we believe that the audience group consisting of practitioners will be highly interested in an extensive historical account of the microelectronics industry.

Part 8: Conclusion

There are two distinct types of knowledge networks through which firms can identify and absorb new knowledge. One such knowledge network is domestically oriented, and constitutes of commercial and non-commercial actors situated in geographical proximity. The other network is internationally oriented, and enables national firms to tap into knowledge pools that reside in foreign countries.

Evidence from the rise of the Norwegian microelectronics industry suggests that activity in both of the distinct knowledge networks occur, but that they take precedence in different phases of industry development. In the early phases, when actors experiment with new microelectronics knowledge, the focus is on domestic environments. In industry growth, entrepreneurship as a localized knowledge spillover mechanism is important. In later phases, as actors become product-oriented providers of standard components, the focus turn abroad, not only for sales purposes but also for technological learning. There are currently few points of intersection between domestic actors.

The findings are especially interesting in a landscape where business literature and industrial policies focus on the advantages of industrial clustering. The case study challenges the cluster mindset, and suggests that knowledge acquired through international knowledge channels might be just as important for firm competitiveness as locally acquired knowledge.

List of references

ABI Research. 2013. Over 30 Billion Wireless-connected Devices to Be Part of the IoE in 2020. 02.05. Available: http://www.abiresearch.com/research/product/1016390-over-30-billion-wireless-connected-devices/ [Accessed 26.05.2013].

Acharya, R. C. and Keller, W. 2009. Technology transfer through imports. *Canadian Journal of Economics,* 42**,** 1411-1448.

Acs, Z. J., Braunerhjelm, P., Audretsch, D. B. and Carlsson, B. 2009. The knowledge spillover theory of entrepreneurship. *Small Business Economics,* 32**,** 15-30.

Acs, Z. J. and Terjesen, S. A. 2007. Born Local: Two Avenues to Internationalization. *Jena Economic Research Paper,* No. 2007-022.

Aglen, A. F. and Graff, S. G. 2012. On International New Ventures and Economic Development [Pre-diploma thesis, Unpublished]. Trondheim: Norwegian University of Science and Technology.

Andersen, O. 1993. On the Internationalization Process of Firms: A Critical Analysis. *Journal of International Business Studies,* 24**,** 209-231.

Angel, D. P. 1991. High-technology agglomeration and the labor market: the case of Silicon Valley. *Environment & Planning A,* 23**,** 1501-1516.

Atmel TechTalk. 2009. *Atmel TechTalk: maXTouch introduction* [Video online]. Atmel Corporation,. Available: http://www.youtube.com/watch?v=7TnSDeS2pTA [Accessed 26.05.2013].

Audretsch, D. B. 1998. Agglomeration and the location of innovative activity. *Oxford Review of Economic Policy,* 14**,** 18-29.

Audretsch, D. B. and Feldman, M. P. 1996. R&D Spillovers and the Geography of Innovation and Production. *American Economic Review,* 86**,** 630-640.

Autio, E., Sapienza, H. J. and Almeida, J. G. 2000. Effects of age at entry, knowledge intensity, and imitability on international growth. *Academy of Management Journal,* 43**,** 909-924.

Bahlmann, M. D. and Huysman, M. H. 2008. The emergence of a knowledge-based view of clusters and its implications for cluster governance. *Information Society,* 24**,** 304-318.

Banerjee, S. and Streetman, B. G. 2009. Solid state electronic devices. *New Delhi: Phi Learning*.

Baptista, R. 2000. Do innovations diffuse faster within geographical clusters? *International Journal of Industrial Organization,* 18, 515-535.

Baptista, R. 2001. Geographical Clusters and Innovation Diffusion. *Technological Forecasting and Social Change,* 66, 31-46.

Bartlett, C. A. 1986. Managing and building the transnational: The new organizational challenge. *In:* Porter, E. (ed.) *Competition In Global Industries.* Harvard Business School Publishing India Pvt. Limited.

Bathelt, H., Malmberg, A. and Maskell, P. 2004. Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography,* 28, 31-56.

Birkinshaw, J. and Hood, N. 2000. Characteristics of foreign subsidiaries in industry clusters. *Journal of International Business Studies,* 31, 141-154.

Bodman, P. and Le, T. 2013. Assessing the roles that absorptive capacity and economic distance play in the foreign direct investment-productivity growth nexus. *Applied Economics,* 45, 1027-1039.

Boschma, R. A. and Ter Wal, A. L. 2007. Knowledge networks and innovative performance in an industrial district: the case of a footwear district in the South of Italy. *Industry and Innovation,* 14, 177-199.

Branstetter, L. 2006. Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's FDI in the United States. *Journal of International Economics,* 68, 325-344.

Bresman, H., Birkinshaw, J. and Nobel, R. 1999. Knowledge transfer in international acquisitions. *Journal of International Business Studies,* 30, 439-462.

Businesswire. 2007. Chipidea to Acquire Data Converter Business Unit From Nordic Semiconductor ASA. *Businesswire* [Online], 15.02 03:00. Available: http://www.businesswire.com/news/home/20070215005239/en/Chipidea-Acquire-Data-Converter-Business-Unit-Nordic [Accessed 26.05.2013].

Bye, B., Fæhn, T. and Grünfeld, L. A. 2008. Growth policy in a small, open economy. Domestic innovation and learning from abroad. *EDIRC - Discussion Papers - Research Department of Statistics Norway*.

CNET. 2004. Logitech V500 Cordless Notebook Mouse review. *CNET* [Online], 11.11. Available: http://reviews.cnet.com/mice/logitech-v500-cordless-notebook/4505-3148_7-31144953.html [Accessed 26.05.2013].

Coe, D. T. and Helpman, E. 1995. International R&D spillovers. *European Economic Review,* 39, 859-887.

Coe, D. T., Helpman, E. and Hoffmaister, A. W. 1997. North-south R&D spillovers. *Economic Journal,* 107**,** 134-149.

Cohen, W. M. and Levinthal, D. A. 1989. Innovation and Learning: The Two Faces of R & D. *The Economic Journal,* 99**,** 569-596.

De Propris, L. 2002. Types of innovation and inter-firm co-operation. *Entrepreneurship and Regional Development,* 14**,** 337-353.

Delgado, M. A., Farinas, J. C. and Ruano, S. 2002. Firm productivity and export markets: A non-parametric approach. *Journal of International Economics,* 57**,** 397-422.

Dosi, G. 1988. Sources, Procedures, and Microeconomic Effects of Innovation. *Journal of Economic Literature,* 26**,** 1120-1171.

Easterlin, R. A. 1981. Why Isn't the Whole World Developed? *The Journal of Economic History,* 41**,** 1-17.

Energy Micro. 2009. Ultra low power microcontroller specialist Energy Micro extends global sales organization. 10.03. Available: http://www.energymicro.com/news-archive/energy-micro-extends-global-sales-organization [Accessed 28.05.2013].

Energy Micro. 2013a. Alf-Egil Bogen, co-inventor of the AVR microcontroller, joins Energy Micro as Chief Marketing Officer. 25.02. Available: http://www.energymicro.com/news/alf-egil-bogen-avr-mcu-co-inventor-joins-as-chief-marketing-officer [Accessed 26.05.2013].

Energy Micro. 2013b. ARM selects Energy Micro as a partner in university education program to champion ARM Cortex M-series processor-based MCUs. 23.04. Available: http://www.energymicro.com/news/arm-and-energy-micro-education-program-to-champion-cortex-m [Accessed 26.05.2013].

Fallick, B., Fleischman, C. A. and Rebitzer, J. B. 2006. Job-hopping in silicon valley: Some evidence concerning the microfoundations of a high-technology cluster. *Review of Economics and Statistics,* 88**,** 472-481.

Fernhaber, S. A., Gilbert, B. A. and McDougall, P. P. 2008. International entrepreneurship and geographic location: An empirical examination of new venture internationalization. *Journal of International Business Studies,* 39**,** 267-290.

Freeman, S., Edwards, R. and Schroder, B. 2006. How smaller born-global firms use networks and alliances to overcome constraints to rapid internationalization. *Journal of International Marketing,* 14**,** 33-63.

Gertler, M. S. and Levitte, Y. M. 2005. Local nodes in global networks: The geography of knowledge flows in biotechnology innovation. *Industry and Innovation,* 12**,** 487-507.

Ghoshal, S. and Bartlett, C. A. 1988. Creation, adoption, and diffusion of innovations by subsidiaries of multinational corporations. *Journal of International Business Studies,* 19**,** 365-388.

Giuliani, E. 2005. Cluster absorptive capacity: Why do some clusters forge ahead and others lag behind? *European Urban and Regional Studies,* 12**,** 269-288.

Giuliani, E. and Bell, M. 2005. The micro-determinants of meso-level learning and innovation: Evidence from a Chilean wine cluster. *Research Policy,* 34**,** 47-68.

Glăvan, B. 2008. Coordination failures, cluster theory, and entrepreneurship: A critical view. *Quarterly Journal of Austrian Economics,* 11**,** 43-59.

Grossman, G. M. and Helpman, E. 1991. *Innovation and growth in the global economy,* Cambridge, Mass., MIT Press.

Gulliksen, S. 2011. Made in Trondheim. *Adresseavisen*, 11.03.2009, p.27.

Halvorsen, F. 2006. Trådløst IT-eventyr. *Teknsik Ukeblad* [Online], 18.01 08:00. Available: http://www.tu.no/nyheter/ikt/2006/01/18/tradlost-it-eventyr [Accessed 26.05.2013].

Halvorsen, F. 2007. Texas tapte mot Førre. *Teknisk Ukeblad* [Online], 21.12 14:10. Available: http://www.tu.no/it/2007/12/21/texas-tapte-mot-forre [Accessed 26.05.2013].

Hamnes, L. and Valmot, O. R. 2012. Dette er Norges ukjente milliardbutikk. *Teknisk Ukeblad* [Online], 24.09 10:42. Available: http://www.tu.no/it/2012/09/24/dette-er-norges-ukjente-milliardbutikk [Accessed 22.05.2013].

Hofstede, G. 1984. *Culture's Consequences: International Differences in Work-Related Values*, SAGE Publications.

Johanson, J. and Vahlne, J.-E. 1977. The Internationalization Process of the Firm-A Model of Knowledge Development and Increasing Foreign Market Commitments. *Journal of International Business Studies,* 8**,** 23-32.

Johanson, J. and Vahlne, J.-E. 2009. The Uppsala internationalization process model revisited: From liability of foreignness to liability of outsidership. *Journal of International Business Studies,* 40**,** 1411-1431.

Keller, W. 2004. International technology diffusion. *Journal of Economic Literature,* 42**,** 752-782.

Khronos Group. 2013. *About The Khronos Group* [Online]. Available: http://www.khronos.org/about [Accessed 26.05 2013].

Kjærvik, A. (ed.) 1997. *Teknologi for samfunnet: en essaysamling - NTH i en brytningstid 1985-1995, 217 pp.,* Trondheim: NTNU.

Kristiansen, M. 2005. Verdens trådløse elite samles i Oslo. *Computerworld* [Online], 09.06 08:24. Available: http://www.idg.no/bransje/bransjenyheter/article3087.ece [Accessed 26.05.2013].

Krugman, P. R. 1991. *Geography and trade,* Leuven, Leuven University Press.

Kuemmerle, W. 1997. Building effective R&D capabilities abroad. *Harvard business review,* 75**,** 61-70.

Lam, A. 1997. Embedded firms, embedded knowledge: Problems of collaboration and knowledge transfer in global cooperative ventures. *Organization Studies,* 18**,** 973-996.

Leirset, E. 2006. Supergründere fra samme kull. *Teknsik Ukeblad* [Online], 03.11 07:00. Available: http://www.tu.no/data/2006/11/03/supergrundere-fra-samme-kull [Accessed 28.05.2013].

LinkedIn Corporation. 2013. *About* [Online]. Available: http://press.linkedin.com/about [Accessed 22.05 2013].

Liu, C. 2006. *Foundations of MEMS*, Pearson Education India.

Lucas, R. E. J. 1988. On the mechanics of economic development. *Journal of Monetary Economics,* 22**,** 3-42.

Lundvall, B. Å. 2007. National innovation systems - Analytical concept and development tool. *Industry and Innovation,* 14**,** 95-119.

Lyse, M. I. 2011. Norges mest spennende selskap. *Computerworld* [Online], 11.05 21:50. Available: http://www.idg.no/computerworld/article207144.ece [Accessed 26.05.2013].

Marshall, A. 1890. *Principles of economics,* London, Macmillan, 6th ed. (1910).

Martin, X. and Salomon, R. 2003. Knowledge transfer capacity and its implications for the theory of the multinational corporation. *Journal of International Business Studies,* 34**,** 356-373.

Maskell, P. and Kebir, L. 2005. 'What qualifies as a cluster theory?'. *What Qualifies as a Cluster Theory?*

Miotti, L. and Sachwald, F. 2003. Co-operative R&D: Why and with whom? An integrated framework of analysis. *Research Policy,* 32**,** 1481-1499.

Moen, S. D., Førre, G. and Tunheim, S. A. 1995. Design of an ASIC for RF-applications with operating frequencies from 20 MHz to 1 GHz. *SINTEF Report.* Oslo: SINTEF.

Morosini, P. 2004. Industrial clusters, knowledge integration and performance. *World Development,* 32**,** 305-326.

Morrison, A. 2008. Gatekeepers of knowledge within industrial districts: Who they are, how they interact. *Regional Studies,* 42**,** 817-835.

Mudambi, R. and Zahra, S. A. 2007. The survival of international new ventures. *Journal of International Business Studies,* 38**,** 333-352.

Nelson, R. 1993. National innovation systems: a comparative analysis. *University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship*.

Niosi, J. and Zhegu, M. 2005. Aerospace clusters: Local or global knowledge spillovers? *Industry and Innovation,* 12**,** 5-29.

Nordic Semiconductor. 2008. Annual Report 2007. Available: http://www.nordicsemi.com/eng/Investor-Relations/Annual-Reports.

Nordic Semiconductor. 2012. Director from Nordic Semiconductor appointed new Chairman of Bluetooth SIG Board. *Corporate related news* [Online], 19.12. Available: http://www.nordicsemi.com/eng/News/Press-Releases/Corporate-Related-News/Director-from-Nordic-Semiconductor-appointed-new-Chairman-of-Bluetooth-SIG-Board [Accessed 26.05.2013].

Nordic VLSI. 2004. Annual Report 2003. Available: http://www.nordicsemi.com/eng/Investor-Relations/Annual-Reports.

NTNU. 2006. *Hovedoppgaver fra IET* [Online]. Trondheim: NTNU. Last updated: 17.02. Available: http://intern.iet.ntnu.no/hovedoppg/ [Accessed 28.05 2013].

Oviatt, B. M. and McDougall, P. P. 1994. Toward a Theory of Interational New Ventures. *Journal of International Business Studies,* 25**,** 45-64.

Owen-Smith, J. and Powell, W. W. 2002. Knowledge networks in the Boston biotechnology community. *Science as an Institution and the Institutions of Science*.

Piore, M. J. and Sabel, C. F. 1984. *The second industrial divide : possibilities for prosperity,* New York, Basic Books.

Porter, M. E. 1990. *The competitive advantage of nations,* London, Macmillan.

Porter, M. E. 1998. Clusters and the new economics of competition. *Harvard business review,* 76**,** 77-90.

Power, D. and Lundmark, M. 2004. Working through knowledge pools: Labour market dynamics, the transference of knowledge and ideas, and industrial clusters. *Urban Studies,* 41, 1025-1044.

Proff Forvalt. 2013. *Proff Forvalt* [Online]. Available: http://www.forvalt.no/ [Accessed 20.05.2013].

Retriever AB. 2013. *About Us* [Online]. Available: http://www.retriever-info.com/en/om-oss/ [Accessed 22.05 2013].

RF Globalnet. 2004. Logitech Chooses Nordic Semiconductor's 2.4 GHz RF Devices For New Cordless Notebook Mouse. *RF Globalnet* [Online], 25.10. Available: http://www.rfglobalnet.com/doc/Logitech-Chooses-Nordic-Semiconductors-24-GHz-0001 [Accessed 26.05.2013].

Romer, P. M. 1990. Endogenous Technological Change. *The Journal of Political Economy,* 98, 71-102.

Sampson, R. C. 2004. Organizational choice in R&D alliances: Knowledge-based and transaction cost perspectives. *Managerial and Decision Economics,* 25, 421-436.

Saxenian, A. 1996. *Regional advantage: culture and competition in Silicon Valley and Route 128*, HARVARD University Press.

Schmitz, H. 2000. Does local co-operation matter? Evidence from industrial clusters in South Asia and Latin America. *Oxford Development Studies,* 28, 323-336.

Silva, A., Afonso, O. and Africano, A. P. 2012. Learning-by-exporting: What we know and what we would like to know. *International Trade Journal,* 26, 255-288.

Solow, R. M. 1956. A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics,* 70, 65-94.

Sölvell, Ö. and Zander, I. 1995. Organisation of the dynamic multinational enterprise: The home-based and heterarchical MNE. *International Studies of Management and Organization,* 25, 17-38.

Tønset, M. 2010. Atmel-sjefen lover utvidelse i Trondheim. *Adresseavisen*, 26.08.2010, p.31.

van Pottelsberghe de la Potterie, B. and Lichtenberg, F. 2001. Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics,* 83, 490-497.

Veugelers, R. and Cassiman, B. 2004. Foreign subsidiaries as a channel of international technology diffusion: Some direct firm level evidence from Belgium. *European Economic Review,* 48, 455-476.

Winge, Å. 1996. Trøndersk chip erobrer verden. *Dagens Næringsliv Morgen*, 16.01.1996, p.6.

Yin, R. K. 2009. *Case Study Research: Design and Methods*, SAGE Publications.

Zahra, S. A. and George, G. 2002. International entrepreneurship: The current status of the field and future research agenda. *Strategic Entrepreneurship: Creating an Integrated Mindset*, 255-288.

Appendix A Screened industries/ technologies

Industry / technology	*Short summary of notable events and other general characteristics relevant to case study*
BIM (Building information management)	- Generation and management of digital representations of physical and functional characteristics of a facility - Widely used globally in construction management and facility operation. - Development from CAD (computer-aided drafting). First implementation by Hungarian firm Graphisoft (1987). Important development by Autodesk (US), Bentley Systems (US) and Nemetschek (German). - Much discussion on interoperability and development of common standards. - Relatively new technology, in conservative industry. Highly anticipated future potential.
Contact lenses	- Lenses placed on the eye; 125 million users worldwide - Gradual development since 1887. Breakthrough in soft lenses by Czech chemists in 1959. Patent bought by Bausch & Lomb (US) in 1971. - Numerous incumbents. Many old corporations with long traditions. Still a lot of development.
District heating	- Long history - Difficult to distinguish technological breakthroughs
Fish farming (Atlantic Salmon)	- The fish farming of Atlantic salmon has a large international footprint, and is in particular considered a traditional and important Norwegian industry - Difficult to distinguish any specific technological breakthroughs (possibly through interviews). - Major change when pioneers were able to farm salmonids in salt water, in the 1960s. Achievements may be identified within enabling technology categories such as water recirculation, processing, fish feed, fish health, cultivation of species and containment (nets, cages, etc.).
FPGA (Field Programm-able Gate Array)	- FPGA – Field-Programmable Gate Array. An integrated circuit to be configured by a customer or a designer after manufacturing - Commercially viable by new-founded American company Xilinix in 1985 - American companies dominate. Xilinix and Altera 80% market share
GPS (Global Positioning System)	- American space-based satellite navigation system - Developed, owned and operated by US government, but open for civil and commercial activity. Fully operational in 1994 - Garmin (founded 1989) central to commercial development. American and Taiwanese activities. International technology acquisitions. - Other companies: TomTom (Dutch), Navigon (German), Satmap (UK) etc.
Hybrid car technologies	- First hybrid car Toyota Prius, 1997 - Multiple technological enablers, difficult to distinguish breakthroughs
Inductive charging	- Uses electromagnetic field to transfer energy between objects

	- Wide range of applications: Consumer goods, transportation, telecommunication - "Invention" by Tesla (~100 years), still immature by commercial potential
LCD (Liquid Crystal Display)	- LCD – Liquid Crystal Display - Twisted Nematic Field Effect as breakthrough: Made LCD practical. Patent by Hoffman-LaRoche (Swiss healt-care company) in 1970. Licensed to Swiss and Japanese firms (for wrist watches). Similar developments in the US. - Major impact on TV industry - Well-documented history
LNG (Liquefied Natural Gas)	- Natural gas that has been converted to liquid form for ease of storage or transport - 1912 – First LNG plant in West Virginia, 1941 – First commercial plant in Ohio, 1959 – First LNG tanker
Magnetic stripes/ chips	- IBM developed method for magnetic stripe under contract with US government in 1960 - Few technological developments since initial breakthrough
Oil service	- Gas compression - Subsea welding - Completion plug - Strong international presence of Norwegian companies
Quartz watches	- Use quartz crystal to provide a stable time base, with few or no moving parts - Seiko (Japan) released the first quartz watch in 1969, after a decade of development. - Quartz revolution: Traditional Swiss watch industry in crisis. American (semiconductor) companies starting mass-production. Hong Kong largest exporter by 1978, American companies out. - Quartz enabled a large number of people to acquire wristwatches
RFID	- Wireless system to transfer data from a tag attached to an object - Wide range of applications: Tracking of goods/people/airport baggage, Toll collection - Gradual development: Breakthroughs 1973 (Mario Cardullo) and 1983 (Charles Walton), US government involvement, company spinoffs. Much US activity initially
Seismic **(oil exploration)**	- Reflection seismology is extensively used in exploration for hydrocarbons (i.e., petroleum , natural gas) and other resources as coal, ores and minerals, geothermal - A method similar to reflection seismology which uses electromagnetic instead of elastic waves is known as ground penetrating radar or GPR. GPR is widely used for mapping shallow subsurface (up to a few meters deep). - The industry can be split into two; land based and marine. They are both based on the same basic idea, but the actual data acquisition processes are quite different. - A number of the main players internationally are Norwegian

Touchscreen/ multitouch	- Multiple technological enablers - Difficult to distinguish breakthroughs
Turbocharge (modern)	- First turbocharged diesel engine passenger car Mercedes-Benz 300 SD, 1978 - Difficult to distinguish technological breakthroughs, long history
Ultrasound/ obstetric ultrasonography	- Academic work in Scotland, 1958. - Commercialized in US in 1963. - Difficult to distinguish technological breakthroughs, long history
Wi-Fi	- Allows an electronic device to exchange data wirelessly over a computer network - Origin in US regulator ruling (1985). Major US corporations involved initially (AT&T, NCR). Australian patents (1992/1996). - Wi-Fi Alliance driving expansion.
Other technologies and industries considered:	- **Concrete** - **Printed memory electronics** - **Solar panel technologies** - **Visualization technologies ICT**

Appendix B Units of analysis

Company	Primary products	Founded	HQ	Chief executive	Employ-ees 2011*	Revenues 2011	Profits 2011
Nordic Semi-conductor	Radio chips	1983 (as Nordic VLSI)	Trondheim	Svenn-Tore Larsen	161	139 m USD	18,9 m USD
Hittite Microwave Norway	Mixed-signal integrated circuits	2007 (as Arctic Silicon Devices)	Trondheim	John Raaum	18	2,4 m NOK**	-13,1 m NOK**
Atmel Norway	Micro-controllers	1995	Trondheim	Vegard Wollan	217	1.114 m USD***	236 m USD***
Texas Instruments Norway	Radio chips	1996 (as Chipcon)	Oslo	Øyvind Birkenes	89	202 m NOK**	39,9 m NOK**
ARM Norway	Graphic processing units	2001 (as Falanx Microsystems)	Trondheim	Kjetil Sørensen	80	162 m NOK**	71,5 m NOK**
FXI Technologies	Single-board computer on a stick	2006	Trondheim	Borgar Ljosland	4	1,2 m NOK	-5,8 m NOK
Energy Micro	Micro-controllers Radio chips	2008	Oslo	Geir Førre	60	46,2 m NOK	-34,8 m NOK
BlueChip (defunct 2009)	Radio chips	1981 (as Gran-Jansen)	Oslo	---	---	---	---

(*) at Norwegian offices
(**) as reported to Norwegian authorities
(***) Atmel's Microcontroller BU, administered from Trondheim. EBIT is presented (not profits)

In addition to the eight companies, two research institutions were considered units of analysis:
SINTEF ELAB in Trondheim
SINTEF Oslo/ SI in Oslo

Appendix C Initial version of the Case Study Protocol

- four sections, as according to Yin (2009)

A: Introduction to case study

The case study will investigate the development of the Norwegian microelectronics industry, and its economic effects. Particular focus will be given to how knowledge is obtained and spread among the members of the clusters, and the channels through which its flows. We will investigate the use of collaborative initiatives, domestic and international knowledge networks, supplier-buyer relations, employee exchanges and governmental bodies.

Theoretically, the case study will be founded on concepts from industrial district theory, knowledge spillover theory, and theory on economic growth. To a large extent, the study will build on the theoretical foundation presented in Aglen and Graff (2012).

The case report will present a chronological depiction of the emergence of the national microelectronics industry. It will address the roots of the microelectronics industry, the roots of the most relevant firms, commercial and scientific research that enabled global competitiveness, and the past experience of central individuals and entrepreneurs.

Besides the historic account, we seek to highlight the current knowledge exchanges and collaborative efforts that make the industry dynamic and competitive, even on a global level. The concept of knowledge spillovers will guide our discussion.

Finally, we seek to describe the societal and economic effects of the industry by looking at the direct value added (e.g. through a review of financial data, employment data) and the indirect effect of product offerings and innovation.

B: Data collection procedures

Three main sources of evidence will be used:

1. *Documents and archival data*
    - A review of sources and commentaries from newspapers and online media (possible through a systematic approach, e.g. a keyword search in online search generators Retriever or Intermedium/Cyberwatcher)
        i. Daily newspapers such as Aftenposten, Dagens Næringsliv etc.
        ii. Technology-focused magazines and online sources such as Teknisk Ukeblad, Elektronikk, New Electronics, RF Globalnet
        iii. Generic Google Search results
    - Data for financial performance of focal firms
        i. Annual income filings in Brønnøysundsregisteret
        ii. Annual reports from publicly listed companies (e.g. Nordic Semiconductor)
        iii. Patent data (Norwegian Industrial Property Office, World Intellectual Property Organization)
2. *Professional networks on online platforms*
    - Review of previous experience of the focal firms' current employees, through the use of LinkedIn Premium. Focus on educational background, previous work

experience (from any of the other cluster firms), and international experience. Quantitative results (anonymous).

3. *Interviews with relevant actors (listed names are potential target interviewees, but going forward we should determine criteria for choosing)*
    - Company insiders (key executives, founders).
        - i. Nordic Semiconductor (Oslo, Trondheim)
            1. Svenn-Tore Larsen (CEO)
            2. Bertel-Eivind Flaten (R&D)
            3. Svein-Egil Nielsen (Emerging Technologies & Strategic Partnerships AND Chairman of the Board Bluetooth SIG)
        - ii. Atmel Norway (Trondheim)
            1. Vegard Wollan (Co-founder)
            2. Alf-Egil Bogen (Co-founder)
        - iii. Energy Micro (Oslo)
            1. Geir Førre (CEO and Founder)
            2. Øyvind Janbu (CTO and Co-Founder)
            3. Zhalina Shaher (Operation)
        - iv. Texas Instrument Norway (Oslo)
        - v. ARM Norway (Trondheim)
        - vi. Others? E.g. Novelda, Arctic Silicon Devices (Hittite)
    - Involvement from academia
        - i. IME faculty members at NTNU
    - Governmental business promotion agencies/ other stakeholders
        - i. Innovation Norway
        - ii. Tekna
        - iii. FPGA Forum

- Establishing contact with potential interviewees:
    - i) Use official channels for establishing contact if no other professional channels are applicable (such as contact network through the university). Such official channels may be company websites, company call center, personal website/profiles on professional network platforms, or the public phone registry.
    - ii) The contact with interviewees should be organized through email (see email-draft under), due to the need for giving the interviewees a thorough introduction (and possibly a source of revision before the interview) of the topic. May be supplemented through telephone conversations if that proves to be of interest in the individual case.
- Preparation for interviews:
    - i) The most relevant information from the review of newspapers and online news media should have been reviewed prior to the interview (summary of the news clippings, or equivalent), and this should be brought to the interview in case of need for reference.

Generic draft for introductory emails: [as all the interviewees ended up being Norwegian all correspondence were conducted in Norwegian, including the interviews]:

Hei,

Vi er to Siv.Ing.-studenter som skriver masteroppgave ved Institutt for Industriell Økonomi og Teknologiledelse (IØT) ved NTNU, Trondheim. Temaet vårt er økonomisk utvikling og verdiskaping, med spesielt fokus på samspillet mellom kunnskapsutvikling, teknologi og industri klynge-strukturer. I stor grad søker vi å utvide begrepsforrådet i vurdering av industriers bidrag til samfunns- og teknologiutvikling, både i nasjonal og internasjonal sammenheng.

Vi ønsker å sette historien til den norske mikroelektronikksektoren sentralt i oppgaven, og bruke trekk ved denne historien til å teste våre teoretiske proposisjoner og modeller. I den anledning har vi sendt denne mailen med forespørsel om hvorvidt du har mulighet til å gjennomføre et kort intervju med oss.

I vårt valg av fokus-case har vi søkt å finne en industri med sterk tilstedeværelse i Norge, og med bredt internasjonalt nedslag. I tillegg har vi sett etter en industri der teknologikompetanse er en sentral komponent i konkurransedyktighet. Valget er falt på den norske mikroelektronikksektoren som oppfyller kriteriene utmerket. I vårt forberedende arbeid er vi blitt mektig imponerte over prestasjonene til klyngedeltakerne, og er fascinert over hvordan sektoren har seilet frem som en av Norges mest spennende og fremtidsrettede. Vi mener at historien fortjener å bli utfyllende fortalt; også fordi vi tror at dette caset bærer på lærdom som potensielt kan overføres til andre industrier.

[Spesifikke punkter om hva vi søker bidrag fra gjennom den enkelte respondent kan komme inn her eller i løpet av neste avsnitt]

I intervjuet vil vi søke å belyse konkrete aspekter ved historikken og tilstanden til sektoren. En mer utfyllende oversikt over temaene vi ønsker å gå inn på kan vi oversende nærmere intervjudagen, men vi tror ikke at intervjuet vil kreve forberedelser fra din side. Vi holder til i Trondheim til vanlig, men vil også kunne få til å gjennomføre intervjuet i Oslo. Har du mulighet én av de to første ukene etter påske (mellom 2. og 12. april)?

Vi har også sendt denne mailen i kopi til vår veileder ved IØT-instituttet, professor Arild Aspelund. Om du har flere spørsmål; ikke nøl med å ta kontakt!

Ditt bidrag vil bli sterkt verdsatt. Vi venter spent på ditt svar, og håper det vil være positivt.

Med vennlig hilsen,
Andreas Flåt Aglen og Sondre Gullord Graff
5. klasse ved Masterprogrammet i Industriell Økonomi og Teknologiledelse, NTNU

ii) Each interviewee's work background should be investigated, e.g. through LinkedIn, company websites

iii) A set of questions should be prepared:
    - For all interviews:
        - Validate case scope: "Name the other companies they considered to be part of the same domestic industry?"
        - Validate the choice of key informants: "What other individuals can it be relevant for us to talk to?"
        - Question seeking the interviewees' own reflections and opinions about the industry as a whole, and their thoughts about the future of the domestic industry
    - Customized for the individual interviewee:
        - Directed at the topics that need to be investigated, e.g. the current and/or prior company of employment, personal history and engagements.

iv) Be prepared for delays or other interruptions during the interview
    - Make sure the most important topics are covered through the scheduled time span of the interview
    - Make sure not to make other plans on the day of the interview

v) Send email to confirm the appointment, two-three days in advance
    - Include the overarching topics for the interview if applicable

vi) Bring audio recording equipment, stationeries, laptop and mobile phone with necessary contact information to company/interviewee in case of unforeseen events.

- During interviews:
    i) Audio recording of the interview, after permission by interviewee
        - If not accepted by the interviewee; one of the investigators should be prepared to retrieve a laptop to take notes (faster than handwriting)
        - If accepted, ask if interviewee want quotation check
    ii) One investigator shall take control of keeping to the line of inquiry, while one should be responsible for taking notes of the major findings, along with time reference for the audio recording.
- After interview
    i) Transcription of the interviews, based on notes and audio recordings.
    ii) If quotation check is requested, email the quotes as soon these are ready (will not happen before there exist a good draft of the areas covered in the interview)

<u>C: Outline of case study report</u>

The basic outline of the case study report (this is liable to be changed when the report is written) is as follows (based on a linear-analytic structure):

- Introduction
- Theoretical background and presentation of propositions
- Presentation of the data as a chronological, readable story, supplemented with quotes and archival data (inspired by AnnaLee Saxenian's case study book "Regional advantage: Culture and competition in Silicon Valley and Route 128" from 1996)

- Discussion of major findings, implications of these findings, and conclusion

<u>D: Case study questions</u>

Units of analysis are the five organizations listed above, including possible additional organizations identified in the course of the data collection process. The data to be collected should follow the propositions:

- How is the *domestic supply of labor with relevant education and experience?*
- What, if any, *significant domestic demand conditions* are there?
- How is the *competition between domestic companies* within microelectronics in Norway?
- What types of *local collaborative activities* are there?
- How is the *intra-industry mobility of workers*?
- Which *historic spin-off processes* have resulted in new domestic firms?
- How is the *presence of domestic research institutions*?
- How, and in which ways, are *international trade* conducted?
- Are there any *international collaborative activities*?
- Which other companies can be defined as part of the industry? (That being MNCs, INVs or other types of companies)

Appendix D Companies and other entities being referred to in the case study

*Entity name**	*Origin and short description of business activities ***
Agere Systems	An American integrated device manufacturer specialized in personal broadband solutions. The business was spun-off among other business units from AT&T to Lucent Technologies in 1996, and Agere Systems was spun-off from Lucent in 2002. Merged with LSI Corporation in 2007.
AGH University of Science and Technology	The largest technical university in Poland. Established in 1919 in Krakow.
Alcatel	A French telecommunications equipment company. Have roots back to two telecommunication companies, one French and one American, both established in the 19^{th} century. Is today branded as Alcatel-Lucent after a merger with Lucent Technologies in 2006
Apple	An American computer software and consumer electronics company. Established in 1976 in California. Among their most prominent products today are iPad, Mac, iPhone, and the OS X operating system.
Arctic Silicon Devices (ASD, Hittite Microwaves Norway)	A Norwegian fabless semiconductor company specialized in data converters. Established in Trondheim in 2007. Targeted the market for mobile ultrasound scanners for medical purposes. Sold to Hittite Microwave Corporation in 2011
ARM	British fabless semiconductor and software design company. Founded in 1990 in Cambridge. Is today the world's leading semiconductor intellectual property (IP) supplier
ARM Norway	See *Falanx Microsystems*
Atmel Corporation	American integrated device manufacturer. Established in California in 1984. Started up as a provider of non-volatile memory chips. Today is AVR microcontroller their largest product area
Atmel Norway	Autonomous design centre part of Atmel Corporation. Established in 1995 in Trondheim, with responsibility to develop the AVR microcontroller. Other products have later been developed at this design center, including the touch screen technology, maXTouch.
Autronica	A Norwegian provider of alarm systems. Established in 1957. The original operations exist today within a number of other companies.
BlueChip Communications (BlueChip)	See *Gran-Jansen*
Bluetooth SIG (SIG)	Abbreviation for "Bluetooth Special Interest Group". This is the organization owning the trademark and overseeing the development of the Bluetooth technology. Established as a privately held, not-for-profit trade association in 1998. The headquarter is in Kirkland, Washington.

Broadcom	An American fabless semiconductor company focused on wireless and broadband communication solutions. Founded in 1991 in California
CES	A major, non-public technology exhibition held in January in Las Vegas. First arranged in 1967
Cambridge Silicon Radio (CSR)	A British fabless semiconductor company. Established in 1998 in Cambridge. The name was later changed to "CSR". Today's product portfolio is focused in the business areas of connectivity, audio and location
CERN	Acronym for "Conseil Européen pour la Recherche Nucléaire /European Council for Nuclear Research". An international research institution. Operates the world's largest particle accelerator. Established in 1954 in Geneva
Chipcon (Texas Instruments Norway)	A Norwegian fabless semiconductor company. Established in 1996 in Oslo by three SI researchers. Initially ASIC-provider, but later specialized in low-power radio chips. Sold to Texas Instruments in 2005.
Chipidea	A prior Portuguese analog semiconductor design company, founded in 1997. Sold to MIPS Technologies in 2007, and to Synopsys in 2009
Chipidea Norway	Established in 2007 when Chipidea acquired Nordic's Data Conversion business unit. Experienced post merger integration problems, and closed a few years later. Many of the employees went to Arctic Silicon Devices.
Cryptovision	A Norwegian producer of encryption systems targeted for pay-TV solutions. Established in Arendal, Norway, and in the late 1980s acquired by Tandberg. Incorporated as a part of the legal entity Tandberg Television in 1991.
ELAB	SINTEF's electronics group. Founded in 1961 in Trondheim, and would be located at the NTH campus. Initiated IC design activities in 1978
Elektronikk	A Norwegian electronics periodical.
Embedded World	The world's largest exhibition of its kind and the meeting-place of the international embedded community. Established in 2002, and arranged annually in Nürnberg, Germany.
Ember	An American software and fabless semiconductor company. Established in 2001 in Boston. Was an active player in the early development of mesh networking software part of the ZigBee-platform. Acquired by Silicon Labs in 2012
Emblaze Semiconductor	An Israeli fabless semiconductor company. Established when Emblaze, the parent company bought Zapex Research in 2001. Develop chip-based solutions for cell phone multimedia transmission. Sold to Zoran Corporation in 2004.
Energy Micro	Fabless semiconductor company. Established in 2009 in Oslo, by the former CEO and co-founder of Chipcon. Produces low-energy microcontrollers and radio chips.
Ericsson	A Swedish provider and operator of telecommunications networks, television and video systems. Established in Stockholm in 1876.

ETH Zürich	A Swiss science university. Established in 1854 in Zürich. Ranked as the best university in continental Europe by Time Higher Education ranking 2012/13
Falanx Microsystems (ARM Norway)	Design center part of ARM. Founded in 2001 in Trondheim by five NTNU students. Designs GPUs for mobile devices
FFI	Abbreviation for "The Norwegian Defense Research Establishment / Norges Forsvars Institutt". National center for applied technical research, with defense related science as focus area. Established in 1946. Research on transistors became prominent in the beginning of the 1970s.
Figure 8 Wireless	An American software company specialized in Zigbee system software. Established in San Diego in 2002. Acquired by Chipcon in 2005
Forenede Forsikring	A Norwegian insurance company. Established in Trondheim in 1979, as a result of a merger a number of other insurance companies. Is today part of DNB ASA, Norway's largest financial services group.
Freescale Semiconductor	See *Motorola*
FXI Technologies (FXI)	A hardware and software start-up, producing a single-board computer on a stick. Founded in 2006 as a spin-off from Falanx Microsystems. Headquartered in Trondheim
Gløshaugen Innovation Center	A Norwegian on-campus incubator for business development, the first of its kind in Norway. Established in 2001 at the campus of NTNU in Trondheim.
Gran-Jansen (BlueChip Communications, Micrel Norway)	A Norwegian fabless semiconductor company. Established in Oslo in 1981. Produced and launched the world's first radio transceiver chip in 1995. In 2001 sold to Micrel. Dissolved in 2009.
GSMA Mobile World Congress	The world's largest exhibition for the mobile industry in combination with a conference featuring prominent executives of mobile operators, device manufacturers, technology providers, vendors and content owners. First held in 1987, and currently takes place every February in Barcelona.
HiST	Abbreviation for "Sør-Trøndelag University College / Høgskolen i Sør-Trønderlag". A Norwegian university college located in Trondheim. Established in 1994 as a merger between eight of independent university colleges in Trondheim. Offers higher education engineering and information technology, among other things.
Hittite Microwave Corporation	An American semiconductor firm. Established in Massachusetts in 1985. Specialized in integrated RF-circuits with micro and millimeter wave applications.
Hittite Microwaves Norway	See *Arctic Silicon Devices*
HTC	A Taiwanese electronic device manufacturer specialized in smartphones and tablets. Established in 1997, and headquartered in Taoyuan City, Taiwan.
Innovation Norway	Norwegian governmental industry development promoter. Established in

	2004, replacing four other governmental organizations, including SND. Focus on both business economy and national economy
Integrated Circuit Designs	An American analog design company. Founded in 1995 in Baltimore. Acquired by Texas Instruments in 2007.
Intel	An American integrated device manufacturer. Established in 1968 in California. Is today the world's largest semiconductor company based on revenue, a position they have held throughout the last decades.
IT Fornebu	A project started in 1996 at the old airport of Oslo, Fornebu. The vision was to establish a cluster of IT firms close to Oslo. Part of this project was a business incubator. The project did not evolve as planned, and the incubator business was handed over to Oslo Science Park in 2010.
Khronos Group	A standardization consortium, dedicated to connecting software to silicon. Established in 2000 as a not for profit, member-funded consortium.
Lenovo	A Chinese electronics manufacturer. Established in 1984 in Beijing. Production and sales of computer hardware and electronic devices is their main business, with smartphones, computers and servers as major product areas.
Logitech	A Swiss provider of personal computer accessories. Established in 1981 in Apples, Switzerland.
Micrel	An American integrated device manufacturer. Established in 1978 in California. Is today designing and producing a wide range of semiconductor based chips.
Micrel Norway	See *Gran-Jansen*
Microchip Technology	An American provider of microcontroller and analog semiconductors. Established in 1989 and is headquartered in Arizona.
Microsoft	An American software company. Established in New Mexico in 1975. The company is the world's largest software company, with their operating system, Windows, and office suite, MS Office, dominating their respective parts of the PC software market.
MIPS Technologies	An American fabless semiconductor company. Established in 1984 in California. License processor architecture to chip makers, of which home electronics and portable media players are dominant. Acquired by Imagination Technologies in 2012
Motorola	An American telecommunications company. Established in Chicago in 1928. In 1999 and 2004 were large parts of their semiconductor activities spun off into two separate entities; ON Semiconductor and Freescale Semiconductor.
NCE MNT	Abbreviation for "Norwegian Centers of Expertise Micro- and nanotechnology". A program established to support innovative activity in the cluster centered in the municipality of Horten. 29 companies in total are engaged in the program. Sensor technology is one of the most prominent product areas among these firms.
NERA	Acronym for "Norsk Elektronisk Radio Aparatur". A Norwegian telecommunication equipment manufacturer. Founded in 1947 in Bergen.

	Had a contract with FFIs department for radio technology in Bergen for the production of microwave radio links, used to build the first radio links in Norway. Was in 2011 sold to the Israeli firm Ceragon.
New Index	A Norwegian start-up with roots to NTNU. Established in 2003 in Trondheim. Based on an idea of a wireless electronic pen that could make any wall into an interactive whiteboard through connection with a projector. Sold in 2011to Seiko Epson.
Nokia	A Finnish communications and information technology corporation. Established in 1865 as a paper manufacturer, but moved during the 20th century over to their current business area. Mobile telephones and portable IT devices are today their principal products, in addition to a number of other services related to telecommunications and computer software.
Nordic Semiconductor (Nordic, Nordic VLSI)	Fabless semiconductor company. Established in 1983 in Trondheim by four ELAB researchers. Initially ASIC-provider. Today specialized in low-power radio chips.
Norsk Data	A Norwegian mini computer manufacturer. Established in 1967 in Oslo. Dissolved in 1992.
Northern Electric Company	A Canadian electronics producer specialized in telecommunications and data networking equipment. Established in 1895 in Montreal as a spin-off from Bell Telephone Company of Canada. The company went bankrupt in 2009.
The Norwegian Defense Research Establishment	See *FFI*
The Norwegian Industrial and Regional Development Fund	See *SND*
Norwegian Research Council (Norges forskningsråd)	A Norwegian government agency responsible for awarding grants for research. Established in 1993 in Oslo. Covers all research areas, after a merging five predecessors covering specific areas.
Norwegian Tele-communications (Televerket)	A Norwegian telecommunications company. Founded as a state-operated monopolist for telecommunication services in 1855 in Oslo. Transformed to a public corporation in 1994, and renamed to Telenor in 1995. Operates today in a number of countries in Europe and Asia.
Norwegian Tele-comunications' department for Research and Innovation (Televerkets forskningsinstitutt)	A department of Norwegian Telecommunications and a national center for applied research within telecom. Established in 1967 in Oslo, in the same building as FFI. ASIC development was one of their research areas. The research operations continued after the privatization of Norwegian Telecommunications, but now as a private establishment. Is today Norway's largest research establishment within information and communications technology.
Novelda	A Norwegian fabless semiconductor company specialized in sensor technology. Established in 2004 as a spin-off from UiO. Provides today a

	CMOS radar system integrated on a chip.
NTH	See *NTNU* Abbreviation for "Norwegian Institute of Technology / Norges Tekniske Høgskole"
NTNU (NTH)	Abbreviation for "Norwegian University of Science and Technology / Norges Teknisk-Naturvitenskapelige Universitet". The second largest university in Norway. Established in 1910 in Trondheim. Holds the responsibility for all higher technology education in Norway.
Nvidia	An American semiconductor company. Established in 1993 in California. Is together with its chief rival AMD, dominating the global market for GPUs.
Oslo Science Park (Forskningsparken)	A Norwegian research park. Established in 1985 in Oslo, next to the campus of the University of Oslo. Intended to strengthen the cooperation between industry and research.
Otrum Electronics	A Norwegian hotel-TV solution provider. Established in 1985 in Arendal, Norway.
Philips Electronics	A Dutch electronics company. Established in 1891 in Eindhoven. Is today one of the largest electronics companies in the world. Sold their integrated device manufacturer business in 2005, after this activity had been spun off into a separate company, NXP Semiconductor.
Plessey Semiconductors	A British integrated device manufacturer. Originally established as a part of the electronics, defense and telecommunications company, Plessey, in 1957. Plessey was split up and sold in 1989, and Plessey Semiconductor operated under different ownerships and names until 2010, when the company was renamed to Plessey Semiconductors.
Q-Free	A Norwegian provider of solutions and products for electronic toll collection. Established in 1984 in Trondheim.
Quantum Research Group	A leading British developer of capacitive touch solutions. Established in 1996 near Southampton. Acquired by Atmel Corporation in 2008.
Renesas Electronics	A Japanese integrated device manufacturer. Established in 2010 in Tokyo, as a result of the merger of NEC Electronics and Renesas Technology. Is the world's largest producer of microcontrollers.
RF Micro Devices	An American integrated device manufacturer specialized in radio chips. Established in North Carolina in 1991.
Samsung Electronics	A South-Korean electronics company. Established in 1969 Suwon, South Korea. The semiconductor part of the company has been ranked as the second largest in the world since 2002 based on revenue. In addition is LCD and LED panels, televisions and mobile phones other major product areas.
Seiko Epson	A Japanese electronics company, specialized in computer printers, information and imaging related equipment. The first printer was developed by the parent company, Seiko, in 1964.
SGS Thomson	A French-Italian integrated device manufacturer. Established in 1987 by the merger of SGS Microelettronica (Italy) and Thomson Semiconductors (France). From 1998 onwards is the company known as ST

	Microelectronics, and is today the largest European semiconductor firm.
Shockley Semiconductor Laboratory (SSL)	American semiconductor company. Established in an area south of San Francisco in 1956, later known as Silicon Valley. The first company to develop silicon semiconductor devices. Founded by William Shockley.
SI (SINTEF Oslo)	Abbreviation for "Central Institute for Industrial Research / Senter for Industriforskning". National center for applied technical research. Origins from UiO. Established in 1949. Initiated IC design activities in early 1960s. Merged with SINTEF in 1993.
SINTEF	Acronym for "The Department for Scientific and Industrial Research / Stiftelsen for industriell og teknisk forskning". National center for applied technical research. Origins from NTNU. Established in 1950. Initiated IC design activities in early 1960s
Simrad	A Norwegian provider of technical solutions for fisheries. Established in 1947 in Oslo, and moved later to Horten. Has since 1996 been part of Kongsberg Maritime.
SND	Abbreviation for "The Norwegian Industrial and Regional Development Fund / Statens nærings- og distriktsutviklingsfond". Norwegian governmental industry development promoter. Provides start-up advice to the inexperienced entrepreneurs. Formed part of Innovation Norway from 2004 onwards
Sony	A Japanese electronics manufacturer. Established in 1946 in Tokyo. Today is imaging, games, mobile products and communications, home entertainment and sound major product areas.
Stentofon	A Norwegian intercom systems provider. Established in 1946 in Trondheim. Forms today part of Zenitel.
St. Olav's University Hospital	The hospital in Trondheim. There is a close cooperation with NTNU in education of medical doctors and in medical research.
Synopsys	An American electronic design automation company. Established in 1986 and headquartered in California.
Tandberg	A Norwegian manufacturer of videoconferencing systems, established in 1979 in Oslo. Tandberg was acquired by Cisco in 2010. Tandberg and Tandberg Data have common roots from the bankruptcy of Tandberg Radiofabrikk in 1978.
Tandberg Data	A Norwegian information storage provider. Established in 1979 in Oslo. Went bankrupt in 2009
Tandberg Telecom	A fully owned subsidiary of Tandberg ASA
Telenor	See *Norwegian Telecommunications*
Telenor Venture	A venture arm of Telenor aiming at developing new ventures in the IT and telecommunications industry. Established in 1992 in Oslo.
Texas Instruments (TI)	American integrated device manufacturer. Established in 1951 in Texas. In 2012 the world's fourth largest semiconductor company.

Texas Instruments Norway (TI Norway)	See *Chipcon*
Toshiba	A Japanese electronics manufacturer. Established in 1939 in Tokyo. The business unit of electronic devices conducts both design and production of memory, logic and imaging, among other things.
UiO	Abbreviation for “University of Oslo / Universitetet i Oslo”. The oldest and largest university in Norway. Established in 1811 in Oslo.
University of Pennsylvania	An American private research university. Established in 1740 in Pennsylvania. The world’s first electronic general-purpose computer was developed there in 1946
Xilinx	An American fabless semiconductor company specialized in programmable logic devices. Established in 1984 in California. Proclaimed for the inventions of the FPGA and the fabless manufacturing model.
Zigbee Alliance	A group of companies that maintain and publish the ZigBee standard. Established in 2002 as an open, non-profit association of members.
Zoran Corporation	An Israeli fabless semiconductor company. Founded in 1983 and headquartered in California. Product focus of chips for digital cameras and other consumer electronics. Merged with CSR in 2011.

(*) Abbreviation used in the text and other historical names of the entities is referred to in brackets.
(**) The information is based on information from company websites, web pages for business information, and general web-based encyclopedias.

Appendix E Persons being referred to in the case study

Name	*Company and position (in reverse chronological order)**
Aaa, Einar	NTNU: former professor Atmel Norway: former researcher (one-year engagement) ELAB: former researcher
Aaserud, Oddvar	Nordic Semiconductor: co-founder and former CEO ELAB: former researcher
Arora, Ashish	Logitech: VP of marketing for retail pointing devices
Berntsen, Frank	Nordic Semiconductor: co-founder and chief scientist ELAB: former researcher
Birkenes, Øyvind	Texas Instruments: General Manager of Low Power RF
Bjerke, Jan	Falanx Microsystems: mentor (representing IT Forenbu)
Blazevic, Mario	Falanx Microsystems: co-founder
Bogen, Alf-Egil	Energy Micro: CMO Novelda: member of the board Atmel Corporation: former CMO Chipcon: former member of the board Atmel Norway: co-founder Nordic: former sales representative, former researcher
Conway, Lynn	Co-author of the book "Introduction to VLSI System Design", a pioneering book of VLSI methods.
Fletcher, Ian	Energy Micro: EMEA sales manager
Førre, Geir	Energy Micro: co-founder and CEO Chipcon: co-founder and former CEO SI: former researcher
Gran-Jansen, Petter	Gran-Jansen: founder and former CEO
Gjeitnes, Åsmund	ELAB: former director
Howarth, Lance Gregory	ARM: VP Media Processing Division ARM Norway and FXI Technologies: member of the board
Ingebrigtsen, Kjell Arne	NTNU: professor emeritus ELAB: former researcher
Janbu, Øyvind	Energy Micro: CTO Chipcon: researcher
Larsen, Svenn-Tore	Nordic: CEO
Laub, Steven	Atmel Corporation: CEO
Lindquist, Olav	Hittite Microwave Norway: co-founder and director of business development

	Nordic: former R&D director Data Converters
Ljosland, Borgar	FXI Technologies: co-founder and CEO Falanx Microsystems: co-founder and former CEO
Lowe, Gregg	Texas Instruments: VP of analog products
Lundh, Yngvar	FFI: former researcher
Mead, Carver	Co-author of the book "Introduction to VLSI System Design", a pioneering book of VLSI methods.
Meyer, Jan	Nordic: co-founder ELAB: former researcher
Moen, Sverre Dale	New Index: Director of product development, former CEO Chipcon: co-founder and former VP of sales and marketing SI: former researcher
Moldsvor, Øystein	Hittite Microwave Norway: co-founder and CTO Nordic: former R&D director Data Converters
Moore, Gordon E.	Intel: co-founder Shockley Semiconductor Laboratory: researcher *(Moore's law is often used as a prediction for the trajectory of the semiconductor market)*
Myklebust, Gaute	Atmel Corporation: VP of Microcontroller product planning Atmel Norway: former researcher (the third person to start in Atmel Norway)
Mæhlum, Robert	Falanx Microsystems: co-founder
Natvig, Lasse	NTNU: professor
Nielsen, Svein-Egil	Nordic Semiconductor: Director of Emerging Technologies and Strategic Partnerships
Nystad, Jørn	Falanx Microsystems: co-founder
Opsahl, Jan Kristian	Tandberg: former CEO
Perlegos, George	Atmel Corporation: former CEO
Philipp, Harald	Atmel: CTO of Touch Technology Quantum Research Group: founder and former CEO
Raaum, John	Hittite Microwave Norway: co-founder and CEO Nordic: former researcher
Shockley, William	Shockley Semiconductor Laboratory: founder *(one of three scientists behind the discovery of the transistor)*
Stavik, Olaf	Co-founder of a number of sensor firms around Horten SI: former researcher
Sæther, Trond	Nordic Semiconductor: co-founder and director of IPR FXI Technologies and Novelda: member of the board NTNU: former professor

	Falanx Microsystems: former member of the board ELAB: former researcher
Sørgård, Edvard	Falanx Microsystems: co-founder
Søråsen, Oddvar	FFI: former researcher
Torvmark, Karl	Texas Instruments Norway: Strategic Marketing
Troøyen, Oddbjørn	Nordic: former CEO
Tunheim, Svein Anders	Chipcon: co-founder and former CTO
Uthus, Jo	Atmel Corporation: Director of Applications, Microcontroller business unit Atmel Norway: former researcher
Wollan, Vegard	Atmel Corporation: VP of microcontroller business unit Atmel Norway: co-founder Nordic: former sales representative, former researcher
Østrem, Geir Sigurd	Nordic: former researcher specialized in analog design

(*) The information is based on information from company websites, web pages for business information, and general web-based encyclopedias.

Appendix F Overview of spin-off organizations