Lappeenranta
University of Technology

Matti Karvonen

# CONVERGENCE IN INDUSTRY EVOLUTION

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ABSTRACT

Matti Karvonen

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The objective of the thesis is to enhance understanding of the evolution of convergence. Previous research has shown that the technological interfaces between distinct industries are one of the major sources of new radical cross-industry innovations. Despite the fact that convergence in industry evolution has attracted a substantial managerial interest, the conceptual confusion within the field of convergence exists. Firstly, this study clarifies the convergence phenomenon and its impact to industry evolution. Secondly, the study creates novel patent analysis methods to analyze technological convergence and provide tools for anticipating the early stages of convergence. Overall the study combines the industry evolution perspective and the convergence view of industrial evolution.

The theoretical background for the study consists of the industry life cycle theories, technology evolution, and technological trajectories. The study links several important concepts in analyzing industry evolution, technological discontinuities, path-dependency, technological interfaces as a source of industry transformation, and the evolutionary stages of convergence. Based on reviewing the literature a generic understanding of industry transformation and industrial dynamics was generated. In the convergence studies, the theoretical basis is in the discussion of different convergence types and their impacts on industry evolution, and in anticipating and monitoring the stages of convergence.

The study is divided in two parts. The first part gives a general overview, and the second part comprises eight research publications. Our case study is based historically on two very distinct industries of the paper and electronics companies as a test environment to evaluate the importance of emerging business sectors and technological convergence as a source of industry transformation. Both qualitative and quantitative research methodology are utilized. The results of this study reveal that technological convergence and complementary innovations from different fields have significant effect to the emerging new business sector formation. The patent-based indicators in the analysis of technological convergence can be utilized on analyzing technology competition, capability and competence development, knowledge accumulation, knowledge spill-overs, and technology-based industry transformation. The patent-based indicators can provide insights to the future competitive environment. Results and conclusions from empirical part seem not be in conflict with real observations in the industry.

**Keywords:** convergence, industry evolution, life cycle models, technological discontinuities, technological trajectories, industry transformation, patent analysis, patent citations

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**FOREWORD**

It can be said that there is quite a long history in my ‘convergence’ studies. I made my master thesis at the Joensuu University related to ecomic growth and convergence hypothesis between Finnish regions. Now this thesis is again related to ‘convergence’, but from totally different perspective. I feel lucky to have the opportunity to enlighten me in this fascinating world of science. Many people have enabled the completion of this thesis and now it is time to express my gratitude for the support.

First of all I want to owe my gratitude to my supervisor, Professor Tuomo Kässi for offering me the chance to become a member of the research communities of Technology Business Research Center (TBRC) and the Department of Industrial Management at LUT. Professor Kässi generously provided me the environment that has allowed my research and opportunity to conduct exciting research projects in close collaboration with industry. He has allowed me to freely explore the research topics I have been most interested in and has always had time to comment all my research. I highly appreciate his support and advice. I would like to thank the pre-examiners of this dissertation, Prof. Tugrul Daim and Prof. Josu Takala for their valuable comments and recommendations. I got many useful comments that improved my manuscript at the final stage.

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Thanks also to my girlfriend, Thampimol, she has been a wonderful companion and never questioned why I do not have a ‘real job’. Finally, and most importantly, I would like to thank my parents who have provided inspiration to me throughout my life. Eija and Osmo Karvonen, and all the other friends who have made my seemingly endless educational journey possible. Once again heartfelt thanks to my parents who have teached and supported me throughout my life.

Lappeenranta, November, 2011

*Matti Karvonen*

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**PART II: PUBLICATIONS**

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**CONTRIBUTION OF THE AUTHOR IN THE PUBLICATIONS**

The author of this dissertation has been primary author in all of the publications. The researcher has made research plan together with the co-authors and has been responsible for formulating the research problems, theoretical base, coordinating the collection of empirical material and drawing conclusions. The role of co-authors has mainly been in commenting, giving valuable feedback to the articles and helping in collecting empirical data.

1. Made the research plan together with the co-authors. Collected and analysed the data together with co-authors. Wrote the paper together with co-authors.

2. Made the research plan together with the co-authors. Collected and analysed the data together with co-authors. Wrote the paper together with co-authors. Was mainly responsible for revising the paper during the journal review process.

3. Made the research plan and coordinated writing of the paper together with co-authors. Collected and analysed the data together with co-authors. Wrote the paper together with co-authors. Was main responsible for revising the paper during the journal review process.

4. Made the research plan. Collected and analyzed the data. Wrote most of the paper. Was mainly responsible for revising the paper during the journal review process.

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8. Made the research plan. Collected and analyzed the data. Wrote most of the paper.

# 1 INTRODUCTION

## *1.1 Background of the study*

This dissertation deals with technology management and industry evolution in converging environments. The main aim of this dissertation, which consists of eight publications and an overview, is to increase understanding of the phenomenon and the stages of convergence. The phenomenon can be regarded as a special form of technological change during which inventions emerge at the intersection of distinct industries (Hacklin, 2008). The need for this dissertation stems from the needs of Finnish information and communication technology (ICT) and forest companies.

In today's world a substantial share of economic activity involves research and knowledge-intensive goods and services with technology as a major factor of competitiveness. Technological competence is the basis for engaging in specific product areas and sectors, and the analysis of technologies is the first step in understanding the economic activities and performance of countries and industries. The innovation policy rhetoric has identified the following key change drivers as a new growth paradigm (Ahola & Rautiainen, 2009): 1) globalization and localization in innovations, 2) customer and user driven innovations (lead markets), 3) value networks and clusters as innovation ground, and 4) technological interfaces. One of the fundamental growth drivers and a source of radical innovations are new scientific-technological opportunities (Figure 1) arising at the interface of distinct industries.

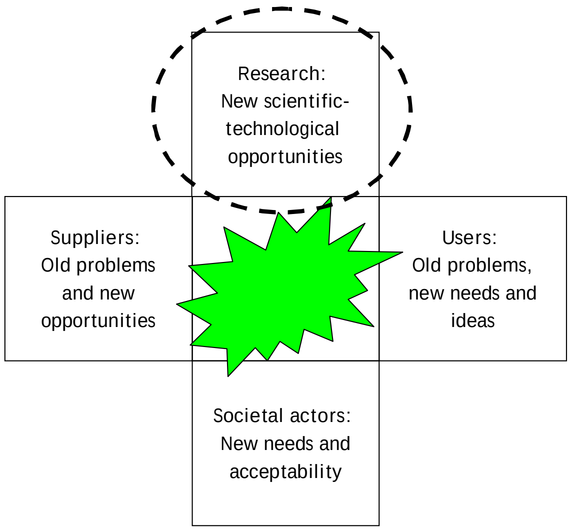


**Figure 1:** Potential developers of innovation and their perspective on the interactive innovation process (Ahola & Rautiainen, 2009)

Hacklin (2008) defines the phenomenon of convergence as a special form of technological change during which inventions emerge at the intersection of established and clearly defined industry boundaries (Figure 2).

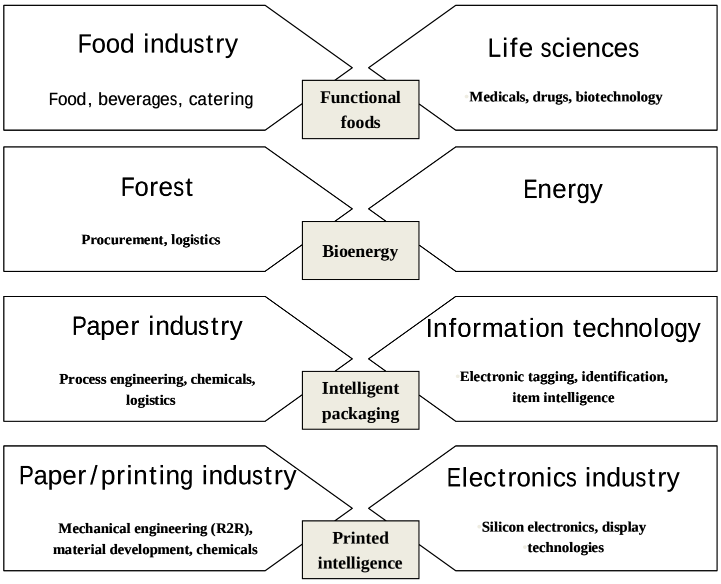


**Figure 2:** Examples of convergent developments (Adapted from Hacklin, 2008)

The starting point of this dissertation is that new business sectors are emerging more and more in the intersection areas of industries (Bröring et al., 2006; Hacklin, 2008) which are demanding new approaches to industry analysis and innovation management methods. In the completed research project called "Creation of new business concepts in the intersection of industries: Electricity Networks and Generation, ICT and Forest Industries" the changing industry structures of these three tightly interconnected industries were examined. One of the emerging intersection areas for new businesses was printed functionality at the intersection of paper and electronics industries. The need for this dissertation stemmed from the needs of renewal in traditional Finnish industries where the pressure of developing new businesses is enormous. One important element with which the original technology owner can keep control of its ownership of the technology is the tools of **intellectual property rights** (IPR). There can be some other tools relating to complementary assets that some actors do have and the other ones do not. With IPR or complementary assets some part of the value added may remain in the high cost country in the case that manufacturing is split among many countries and only technology development or other crucial functions are in the original innovator and technology developing country.

## *1.2 Previous research and the research gap*

There is vast literature on industry evolution and technological change from different theoretical perspectives, such as the economics of industrial organization (Cohen & Levin, 1989; Porter, 1980), innovation and technology (Dosi, 1982; Dosi et al., 1998; Daim et al., 2009), strategic management (Porter, 1998; Teece, 1986), population ecology (Anderson & Tushman, 1991), and evolutionary economics (Nelson & Winter, 1982). These theoretical perspectives have mainly focused on development patterns inside a given industry, while ignoring the change that is taking place at the boundaries between industries and, as Weawer (2007) points out, there are relatively few theory-building initiatives (Stieglitz, 2003; Hacklin, 2008) and texts on industry convergence as a phenomenon in itself. This study reviews the literature on convergence to date, in order to develop a framework for analyzing the stages of convergence. Technological convergence as a source of industry transformation can be regarded as the main underlying rationale for this research.

Evaluating the future technology and market development in converging industry environments has recently become an increasingly important research area. Because of the major competitive and cooperative impacts, to effectively anticipate evolutional or converging technologies and their impacts on the structural change is of high importance. The concept of *convergence* has represented a subject of interest within information and communication (ICT) sectors for over a decade now (Duysteers & Hagedoorn, 1997; Gambardella & Torrisi, 1998; Wirzt, 2001; Stieglizt, 2002; Hacklin, 2008), but recent industrial trends suggest that the phenomenon starts increasingly affecting value creating processes also in other industrial sectors, and there is a lack of empirical work in other convergent industry settings. Therefore, the topic of this dissertation, convergence in industry evolution, is very current.

Technological convergence is a growing phenomenon that has had a profound effect on several industries. However, there is insufficient understanding of the phenomenon of convergence and the literature has so far failed to come up with a strong theoretical foundation for many aspects related to the convergence process. This fact is also shown in this study regarding the definitions and implications of convergence (Chapter 3). The definitions and taxonomies are important to distinguish between different archetypes of convergence, because their implications for industry structure and individual firms are very different. There is also divergence in the academic and management literature of the implications of convergence. Few of the attempts to provide classification of the phenomenon have taken into consideration the temporal dimension. In many cases, it remains hence unclear, whether the suggested different forms of convergence are mutually exclusive, to what extent they may coexist, and whether they occur in any sequential order (See Hacklin, 2008).

All in all, there are many theoretical and managerial gaps in the literature related to the convergence phenomenon: 1) Theoretical perspectives have been focused on development patterns inside a given industry, while ignoring the change that is taking place at the boundaries between industries. 2) Despite the fact that convergence is seen as a major driver of change in many industry settings, there have been relatively few studies from other than the ICT industries. 3) The conceptual confusion within the field of convergence. From a theoretical perspective there seem to be little consensus in what convergence means for and how it affects to the different industry sectors. Similarly the effects on firm strategy and behaviour have not been addressed adequately. The literature also presents very contradictory conceptions of the effects of the convergence phenomenon and it is necessary to understand the nature of change in converging environments. 4) Few of the attempts to provide classification of the phenomenon have taken into consideration the temporal dimension.

Anticipating convergence would enable firms to form strategic alliances or acquire new technologies at early stages in the process of convergence. It is strategically important to anticipate fading technological areas and industry boundaries at the earliest possible moment (Curran & Leker, 2008) in order to help to do right strategic management decisions. 5) Patent citation indicators have not been used in analysing the early stages of convergence and emerging business sectors. 6) The linkages between industry evolution, technological discontinuities, convergence, and innovation management can be regarded as a rather rarely explored subject. All in all, there is insufficient understanding about the mechanism of transformation of industries and value chains in the convergent environments and this makes it difficult to make strategies in relation to new emerging business.

Previous research (e.g. Rosenberg, 1963; Stieglitz; 2003 Hacklin, 2008; Islam & Miyazaki, 2009) has shown that the technological interfaces between different industries are one of the major sources of **new radical** cross-industry innovations. This has been shown also in that the classical use of technology roadmapping, like dealing with all aspects of integrating technological issues into business decision making (e.g. Kappel, 2001; Porter, 2003; Phaal et al., 2003) have been widening to new ways of promoting technology convergence in technology roadmapping process (Yasunaga et al., 2009). Typically the new frontiers of industry and technology tend to be built on the converging paths of previously discrete technologies, such as MEMS (Micro-Electro Mechanical Systems, the convergence of mechanical devices and semiconductor manufacturing technology), bio-informatics (computer science and biotechnology) and mechatronics (mechanics and numeral control technology based on computing). Roadmapping have been identified as a helpful tool for different technologies to converge and create new business models. (Yasunaga et al., 2009) In the light of high strategic importance and challenges in convergence predictions there seems to be clear demand to better understand its meaning in the transformation of industries. On the industry level this has been seen as an increasing need to anticipate change, which will help organizations to address strategies needed in the future.

The linkages between industry evolution, technological discontinuities, convergence, and innovation management can be regarded as a rather rarely explored subject. The present literature lacks knowledge of the applicability of the existing models of industry evolution to these new and emerging industry sectors growing from the technological intersections. We see that there is clearly room for substantial improvement of our knowledge about industry convergence and technological development of trajectories, and patent analysis toolboxes.

## 1.3 Research objectives

Technology convergence is one of the top megatrends in the global economy leading to fundamental changes in the future competitive arena. Industry boundaries definition is of high importance for determining competitive arena. Competition in converging environments is coming from several directions well beyond traditionally defined boundaries and thus challenges managerial decision making. Due to its high strategic importance, an early identification of trends of convergence and anticipation of changing industry structures matters to all stakeholders, including managers, academics and regulators. Anticipating and monitoring the stages of convergence would enable firms to form strategic alliances or acquire new technologies at early stages (see Curran & Leker, 2010) in the process of convergence. It is also important to understand the nature of convergence process and stage of convergence in order to help to do right strategic management decisions in a timely manner. Industry convergence is a challenging situation for companies. Those who are able to correctly foresee the future developments can gain important benefit and position themselves so as to obtain an important competitive advantage. On the other hand making irreversible investments in the wrong technology can seriously threaten the competitive position of a firm. (Bores & Torres, 2003) The need for deeper understanding of this phenomenon represents underlying rationale of this work.

The main objective in writing this dissertation was to enhance understanding of the evolution of convergence. The study analyzes change processes in an environment characterized by convergence and provides tools for anticipating convergence. Accordingly, the main research questions are:

1. How can the convergence phenomenon and its impact on industrial evolution be clarified?
2. How can patent analysis be utilized in analyzing technological convergence?
3. How can the early stages of convergence be anticipated?

The consequences of convergence are studied at the industry and inter-firm level by taking the emerging printed functionality and radio frequency identification (RFID) sector as an example. Overall the aim is to produce theoretical and managerial knowledge to anticipate potential new industry segments and provide understanding of the implications of convergence to industry evolution. The theoretical background is built from **industry life cycle theory** which has been applied to study the competitive dynamics of industry change between **mature and emerging industries**.

The research questions are divided into sub-questions. The key objective of the first main research question was to examine the phenomenon of convergence and evaluate its effects on industry evolution. The study provides a framework for analyzing the different stages of convergence. The second main research question focuses on **patent analysis** in analyzing technological convergence. The third main research question focuses on **anticipating convergence** and provides insights into the use of patent data in technology forecasting and research.

**1. Clarifying the convergence phenomenon and its impacts on industrial evolution**?

1a. *How do technological discontinuities affect the evolution of industries?*
1b. *How can the convergence phenomenon and impacts of convergence be clarified?*

1c. *How does convergence affect the technology base and innovation strategies of industries?*

Increasing the analytical clarity of the phenomenon requires a systematic analysis of prior research on industry evolution and convergence. The first sub-question examines the potential effects of technological discontinuities on industry evolution. The Delphi method was used to find the evolution and value creation opportunities at the interface between the paper and electronics industries. The sub-question provides views to industry transformation from the perspectives of "creative destruction" and "creative cooperation".

The aim of the second and third sub-question was to increase understanding of the technological trajectories of industries and value chain development in convergent environments. The theoretical discussion and empirical analysis helps us to evaluate the dynamics between traditional and emerging new industries and provide a theoretical framework for analyzing the evolution of technological convergence. The results of the empirical analysis are mainly based on interviews, a Delphi study and patent data. Overall, the research questions provide theoretical considerations and perspectives on the convergence phenomenon and industrial dynamics in converging industry environments.

**2. How can patent analysis be utilized in analyzing technological convergence?**

1. *What is the mechanism of knowledge spill-overs based on technology convergence?*
2. *How can the impact of technology-based industry transformation be evaluated?*
3. *How can patent citations be used to evaluate future value chain competition and the impact of technology-based industry transformation?*

The second research question focuses on analyzing technological convergence with patent citation methods. The first sub-question evaluates how knowledge spill-overs and the rate of technological innovation are evolving in converging environments. The objective is to identify overlapping technologies and discover a mechanism to evaluate the *spill-over paradigm* in industry evolution (knowledge flows between sectors). The sub-question provides a possibility to evaluate the exploration process in industry transformation and get an idea of the stage of convergence. The aim of the second and third sub-question was to evaluate the impact (exploitation) and market value of potential industry transformation. In addition, this study provides views to the changing value chain structures and to the future competitive environment. As a whole, the second research question focuses on developing patent citation methods to analyze technological convergence.

**3. How can the early stages of convergence be anticipated?**

1. *How can the stage and effects of technological convergence be evaluated?*
2. *How can patent citation indicators be used to analyze the early stages of convergence?*

The third research question focuses on anticipating the early stages of convergence. The sub-questions concentrate on the synthesizing theoretical and empirical considerations on how patent citation analyses can be used to investigate convergence. The overall aim is to develop a framework for anticipating and monitoring the stages of convergence.

## *1.4 Scope and research approach*

The scope of this thesis is mainly based on science and technology-based innovations. Some European studies have estimated that only a small fraction (4%) of innovations stem from a narrow scientific field. Harmaakorpi (2011) argues that the new innovation environment focuses on the demand side and the systemic nature of innovations where customer needs are identified in a very practical way and by combining very different knowledge. The underlying logic between the different innovations is very different. The challenge is to simultaneously develop and combine both kinds of innovations (Harmaakorpi, 2011). The study takes a supply-driven approach in analyzing the technological convergence, while gaining an understanding of the importance of the market, society, regulation, changing customer requirements, and other factors influencing industry evolution. Technical trend analyses alone cannot incorporate the organizational and other possible scenarios that will influence future technologies. Daim et al., 2006 demonstrate that technology forecasting results can be improved by integrating multiple methodologies. However, here the main focus is on technological progress, and the phenomena of personal (e.g. Ozen et al., 2010) and organizational (e.g. Daim & Oliver, 2008; Amer & Daim, 2010) perspectives are left aside. It is evident that multiple perspectives framework is needed to be able assess all the key elements impacting the technology assessment process. Overall it is rather challenging to forecast emerging business sectors and technologies as there is not historical data available. In such cases, the use of bibliometrics and patent analysis has provided useful data. (Daim et al. (2006) Harmaakorpi (2011) argues that scientific and technological knowledge focuses usually on a narrow scientific field. However, the real life examples and studies (e.g. Rosenkoft & Nerkar, 2001; Lee 2003) have shown that also the scientific and technological knowledge are actively searched beyond local search by combining the distinct scientific and technological knowledge in searching new technological opportunities.

The study focuses on the renewal of established industries and the dynamics of industry change, as well as the technological trajectories of mature basic industries. This dissertation is a case study of one emerging business sector in the intersection of industries. The **case study** is historically based on two distinct industries of paper and electronics companies as a test environment to evaluate the importance of emerging business sectors and technological convergence as a source of industry transformation. The approach is descriptive in nature and relies mostly on the analysis of a large-scale patent database provided by the European Patent Office.

This dissertation utilizes both quantitative and qualitative **research approaches**. Industry life cycle theories, competition models (strategic analysis), and future study methods are vital in the study and used to develop better ways to anticipate changes in industry structures and methods to support firm strategic management.

In the first phase the main research question is to clarify the nature and phase of change in industrial evolution. Industry life cycle models and innovation studies form the theoretical backbone of this dissertation. The qualitative empirical methods used are focused on the development in industry intersections. In this phase, interviews and the Delphi method are used to analyze converging industry environments. In the second phase, patent analysis methods are used to analyze technological convergence. In the third phase, a conceptual lens for analyzing and anticipating early phases of convergence is provided. In the final phase, a synthesis of the research methods used and empirical results is made. The ultimate purpose of the study is to develop methods for **strategic industry analysis**.

## *1.5 Outline of the study*

The study is divided into two parts. The first part gives a general overview, and the second part comprises eight research publications. The outline of the study is depicted in Figure 3 .

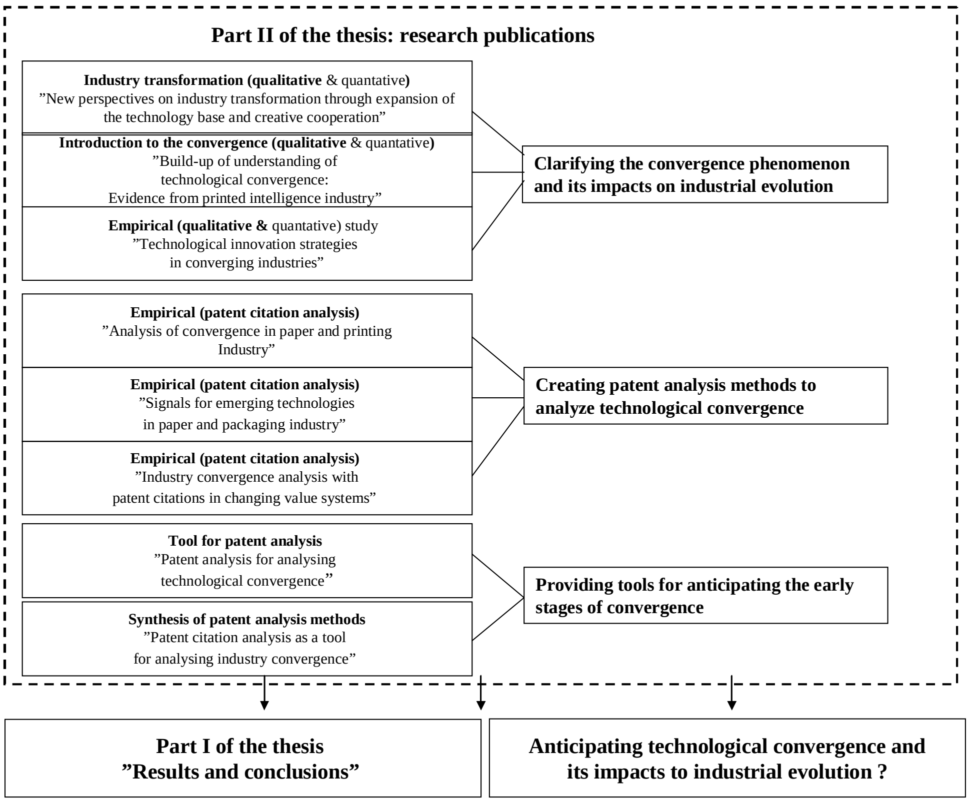


**Figure 3:** The outline of the study

Part I consists of six chapters. The first chapter covers the background, research gap, objectives, and outline of the study, and the second one lays the theoretical background for analyzing industry evolution. Chapter 3 develops a framework for analyzing convergence.

Chapter 4 describes the research strategy and methods applied in the publications, whereas Chapter 5 gives summaries of the publications and reviews the results. The sixth chapter introduces the conclusions and contributions of the study, and discusses its limitations and further research suggestions.

The second part comprises eight complementary research papers. Figure 4 presents the research process. The first one identifies the converging new business sector in the intersection of paper and electronics industries, and uses a qualitative method, the Delphi study, for future studies. The second paper combines qualitative and quantitative data to evaluate how industry convergence and technological trajectories affect the evolution of industries. The third paper continues evaluating the technological trajectories of industries and innovation strategies in convergent environments. The paper uses quantitative financial and patent data from the industry.

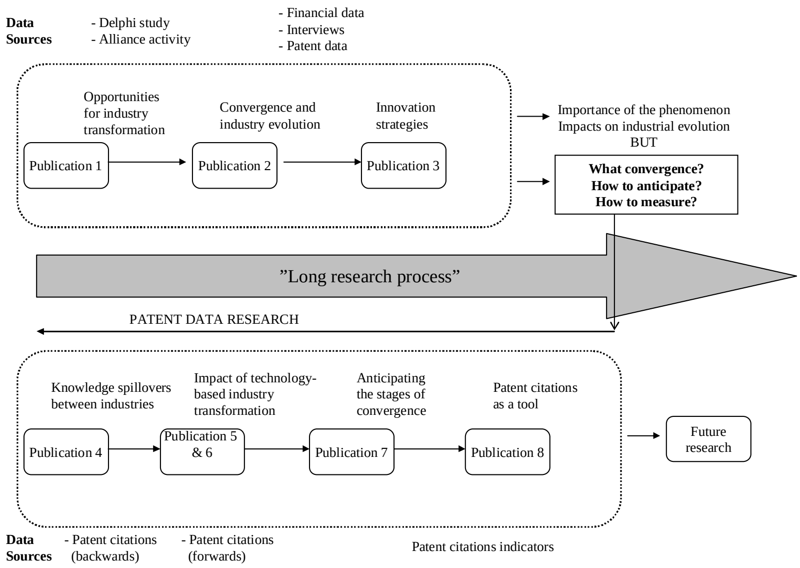

**Figure 4:** The research process

The fourth paper uses patent citation analysis to evaluate the stage of convergence and knowledge spill-overs between sectors based on technological convergence. The different types of citations and impact of this technology-based industry transformation is introduced in the fifth and sixth publication. The seventh paper presents how patent citation analyses can be used to analyze convergence, and the eighth paper synthesizes the analysis of anticipating the stages of convergence with general conclusions.

# 2 THEORETICAL PERSPECTIVES ON INDUSTRY EVOLUTION

Theoretical models on industry evolution offer elements for understanding the nature of competition in an industry and may provide useful insights for strategic management decisions.

## *2.1 Industry life cycle models*

There is a wide range of literature on the **roles of different types of firms** in the areas of industrial organization economics (e.g. Cohen & Levin, 1989), innovation and technology (Dosi, 1982; Dosi et al., 1998), strategic management (e.g. Porter, 1980; Porter, 1985), and population ecology (e.g. Hannan & Freeman, 1977). This chapter introduces the theoretical foundations of the study, but first it shortly defines the basic industry life cycle theories in industry evolution.

Research on the co-evolution of technology and industry structure exploded since the writings of Abernathy & Utterback (1978), and Nelson & Winter (1982), who observed that industry structure often seems to change over the life cycle of a technology. The core ideas of the industry life cycle theory were built in the works of Abernathy, Utterback and Clark (Abernathy & Utterback, 1978; Abernathy & Clark, 1985). According to this theory, the evolution of an industry follows a predictable pattern of growth and maturity. Industry life cycle theories have been applied to the study of **industry dynamics** where the core of the alternation is made between **radical** and **incremental** innovations in industry evolution. We can evidence technologies, products, markets, and industries to undergo life cycles from birth to growth, maturity and finally decline. (E.g. Abernathy & Utterback, 1978) These development cycles can contain long periods of gradual evolution, technological discontinuities, and dominant design formation, and different phases of market evolution are usually characterized by different market structures and different patterns of innovation (Afuah & Utterback, 1997; Munir & Phillips, 2002; McGahan, 2004).

Technology and market dynamics are very different in the context of **incremental and radical** innovations. In incremental change the contributions to improvement are mostly linear and additive, and knowledge prevails in the codified form. Existing capabilities are exploited by **incumbents** while enabling them to build effective barriers to potential entrants. The situation is quite different in disruptive innovation environments where technologies are emergent and more radical in nature. Change is unpredictable and its impact is highly nonlinear, and relevant knowledge is largely in tacit form. In these circumstances entrants enjoy potential competitive advantage over incumbents, as legacy capabilities prove to be liabilities in this environment. (E.g. Christensen, 1997)

Abernathy & Clark (1985) developed a framework for analyzing the **competitive implications of innovation**. The significance of an innovation for competition depends on its *transilience*, which is its capacity to influence the firm's existing resources, skills, and knowledge. The impact of innovation and discontinuity can range from strengthening existing competences to destroying them.

Categorizing past innovations can provide a method for selecting relevant historical precedents to help with predicting market substitution and appropriability (Teece, 1986). In Abernathy and Clark's (1985) framework, innovations can be located into one of four quadrants (Figure 5).

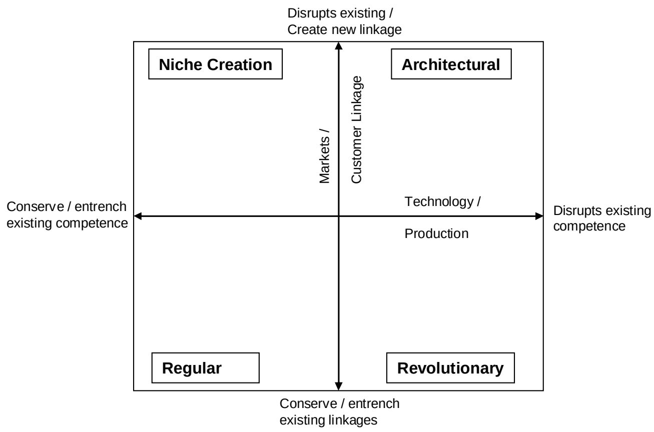


**Figure 5:** Transilience map (Abernathy and Clark, 1985)

**Regular innovation** refers to incremental technical change that builds on established technical and production competence and is applied to existing markets and customers. This type of innovation incrementally reduces costs, as well as improves performance or reliability, while strengthening existing technological and marketing competencies and linkages. **Revolutionary innovations**, such as transistors replacing vacuum tubes and jet engines replacing reciprocating engines in aircrafts, are innovations that overturn established technical and production competencies, but allow a manufacturer to sell to their existing markets and customers. **Niche creation innovation** is the application of existing technologies to new market applications. Lastly, **architectural innovation** involves new technology that disrupts existing competencies and a product that disrupts existing market and customer linkages. Abernathy and Clark use these four types of innovation to mark the extremes of what they term a "Transilience Map," which is defined as the capacity of an innovation to influence the established systems of production and marketing. (Abernathy & Clark, 1985) The authors are able to explain incumbent survival and adaptation when the innovation effect on the firm's transilience is low. Within the scenario of revolutionary innovation, incumbents will not only survive but also experience significant advantages relative to new entrants.

Models on industry evolution offer elements for understanding the **rules of industry change in the environment** and may provide useful insights for strategic management decisions.

Strategy is about establishing direction for the development of a business to the future. Some regularities are evident in the evolutionary paths (Figure 6) that industries follow, and classifying industries according to their **life cycle stages** or **phases** of transition can be an insightful exercise (McGahan, 2004). In McGahan's (2004) terms, change is meaning the change in an industry's external environment and "key to superior performance is in understanding the rules of industry change and adapting to opportunities as they emerge." Firms can therefore have many opportunities for survival and profitability but really significant opportunities arise from changes in their external environment. Understanding the changes directs attention to the forces of **change and direction of industry evolution**, thereby helping us to anticipate and manage change.

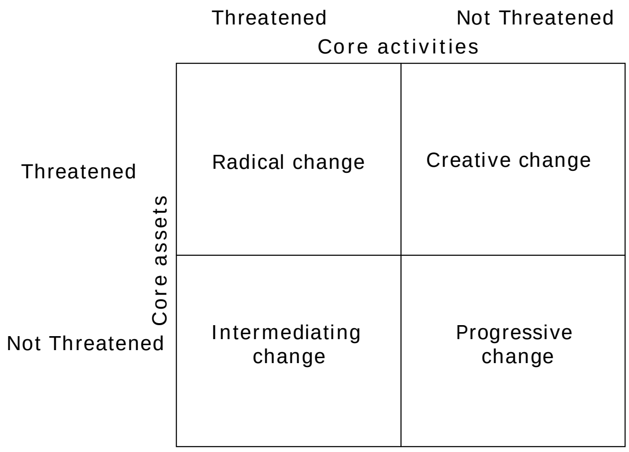


**Figure 6:** Trajectories of industry change (McGahan, 2004).

**Core activity** is essential to an industry's value creation and therefore to its current profitability. Activities are defined as actions taken by firms to create profits. These can be collaborating with suppliers or managing customer relationships, operations, purchasing, selling, marketing, human resources, and distribution. Each core activity has a direct impact on the relationship between the buyers and suppliers, and it can be tied directly to both the revenue and cost streams of the industry. The key is that the new approach must create enough of a threat, and it normally starts with a specialized group of buyers and suppliers, initiating an **architectural change** in the industry.

One of the key characteristics of **core assets** is that they influence interaction between the industry and both its buyers and suppliers at the same time. Assets are defined as items with durable value and property of the firm in the industry, for example, production plants and machinery, raw materials, patents, trademarks, and brand capital. Without core assets the firms in the industry own nothing of proprietary value. **Foundational change** occurs when the durable underlying structure that supports core activities comes under fire and generally arises in the mainstream industry. (McGahan, 2004)

McGahan (2004) defines radical transformation by a threat of obsolescence to both the core assets and activities in an industry. Value chain convergence between the printed and electronic media (Figure 7) is challenging both core activities and core assets in the paper-based media. A radical change is normally very difficult for the industry leader to survive, enter the emerging industry successfully, and then dominate the new industry as a pioneer. McGahan (2004) argues that it is crucial to identify and understand the activities and assets that are working to your advantage, as well as those that constrain your ability to adapt. The relationships that are the most profitable may well be those that create the most constraints.

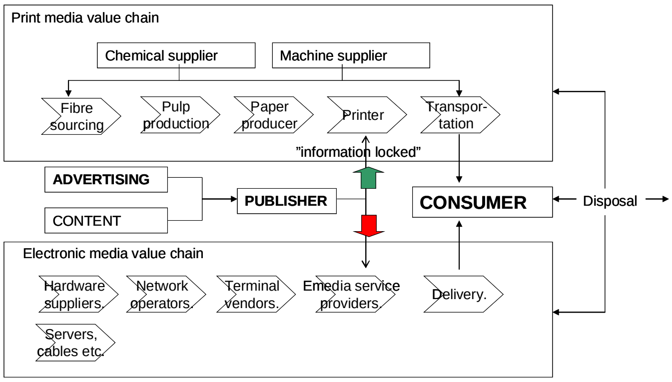


**Figure 7:** Value chain convergence of the printed and electronic media (Adapted from Pöyry, 2006)

The difficulties the incumbent firms have in adjusting their technology strategies to major environmental shifts are called *environmental inertia* (Abernathy & Clark, 1985; Tushman & Anderson, 1986; Henderson & Clark, 1990). Studies have discussed the effects of “competence-destroying” technical changes, which are defined as major technological changes that obviate the technical competencies of established firms (e.g. Anderson & Tushman, 1991; Christensen, 1997). Regardless of the limited possibility of generalization, a key finding from the case studies is that when radical technological developments significantly change the basis of competition, the path dependent nature of firms’ capabilities prevents the incumbents from responding quickly.

In a radical change, industry boundaries are unclear and firms can operate in the new and old business segment. Survival is often dependent on the firms’ capability to find new uses for assets and activity systems when their value creation capacity at the same time gradually declines. Profitability is dependent on the industry’s ability to maintain the value of old assets and activities as long as possible and then exiting efficiently. The process of radical transformation may take decades, but a company that recognizes a transformation early generally has access to a broader range of attractive options than a company that recognizes the evolutionary path late in the process of change. The main challenges under radical change are often to find **optimal asset utilization and diversification as an exit mechanism**, when a company has to diversify to industries that do not preserve the value of assets and activities (McGahan, 2004). Another critical issue is often to find (or find use for) necessary complementary assets (e.g. Grant, 2005).

How volumes in the traditional and emerging industries develop is a key factor in determining the stage of the industry's life cycle, but tracking industry volumes alone will not suffice in assessing the stage of architectural transformation. The challenge is in evaluating how industry structures change and how quickly the new approach might be overtaking the established one. The traditional industry life typically includes the **stages** of fragmentation, shake-out, maturity and decline, whereas the intermediating and radical change evolves through very different stages. The life cycle models of change under the radical trajectory include emergence, convergence, co-existence, and dominance **phases** between the old and new approach (McGahan, 2004**)**. In the conventional life cycle model, the stage depends on inflection points in the *growth of industry volume* whereas in architectural change the phase depends on inflection points in the *relative growth rates in the established industry and in the new industry*. A practical problem that managers face is when investments shift from the current to future technology. If the technology evolves along an S-shaped path, the appropriate time would be the inflection point of the S-curve. After this point, performance improves at a decreasing rate until maturity. The literature is quite consistent in recommending the use of performance as the key dependent variable when testing the S-curves. (E.g. Christensen, 1997; Sood & Tellis, 2005)

**Early phases of industry evolution**

Much of the research has been done to explore the concept of co-evolution of technology and industry structure, with a focus on whether a natural industry life cycle exists (Nelson & Winter 2002, Rosenbloom & Christensen 1998) According to Nelson & Winter (1982), the basic proposition is as follows: During the early period of experimentation and unsteadiness, before a dominant design emerges, there are no particular **advantages to the incumbents**. Market demand is fragmented across a number of variants. Firms producing particular designs tend to be small and model change may be frequent. There is a considerable amount of **exit from and entry** into the industry. An **emerging dominant design** often means evolution during which typically a relatively small number of large firms come to dominate the scene. The industry life cycle provides a useful and important perspective on the points about the variety in the early stages of an industry and path dependence where industry dynamics include self-reinforcing mechanisms that create path dependence. **Natural selection** destroys variety and in a matured industry the evolutionary process may not have much variety to work with.

An industry life cycle can be typically generated by shifts in the relative importance of the three elements of variation, accumulation and competitive selection occurring over the course of time (Nelson & Winter, 1982; Peneder, 2001). It will lead us to perceive the potential emergence of a new industry **going through different, broadly defined stages**, whereby the outcomes of prior phases restrict the possible range of operations during the next phase. Typical for the formation of a novel business in the first phase is the elimination of regulatory barriers to a market entry and business starts-ups, when first movers and followers respond. In the second phase of the "accumulation race" time is required for the formation of regional clusters where codified and tacit knowledge is exploited in education and learning. In the third phase of ”competitive shake-out” the industry typically consolidates as selection imposes a certain direction towards the alleviation of relative scarcities. **Variation** is the perquisite of true change. (Peneder, 2001)

The earliest phases in the evolution of a new branch of industry originate in particular technological breakthroughs or changes in consumer tastes, which create new opportunities for **entrepreneurial profit**. The substitute relationships between individual firms are in the beginning usually slight and markets are highly differentiated (Afuah & Utterback, 1997). During its early stages of development, the stylized model of Afuah and Utterback (1997) argues that **traditional products** and services continue to create the greatest competition for the newly emerging branches of an industry. In the context of printed and electronic media, this realization first and foremost refers to the position of conventional media, such as books and newspapers, as well as the radio and television, which, with older, but more established technologies and marketing forms, attempt to maintain their shares of consumer attention. Demand itself is created by highly discriminating users with specific ideas and a relatively great amount of influence. In this initial situation, the strategic reaction of the supplier depends on how he or she assesses his or her relative position in the market during the transitional phase in which the most dominant designs are gradually established. Following the terminology of Afuah & Utterback (1997), the so-called *strategic leaders* invest specifically in the development and introduction of applications that have potential to generate and set new standards. Latecomers, who are right behind strategic leaders (fast second), still have a chance to expand to complementary fields, for example, providing their products in a cooperative endeavor. As partners, they can wait for an opportunity which enables them to take over the leading position themselves. Strategic latecomers (followers), who see the possibility of closing in on the strategic leaders in the foreseeable future, must in contrast attempt to establish themselves in specialized niches. (Peneder, 2001)

It has often been stated that **new small firms are very important in the start-up period of new industries**, and during the maturation process of the industry the advantages of new small firms tend to decrease and therefore old large corporations will achieve dominant positions. This standard view has also been criticized; for example, not all old large firms are capable of renewal and the roles and assets of new small firms and old large firms can be complementary (e.g. Teece, 1986; Lovio, 1993; Rothaermel, 2001). **Collaboration** between large and small companies has been a response to discontinuous technological change in high technology industries (e.g. Sadowski et al., 2003). The incumbents' **path dependency** provides entry to entrepreneurial companies that challenge the market position of established firms in the industry. The dichotomy between the effects of different types of companies on innovative progress has been widely discussed in the literature for decades (e.g. Nelson & Winter, 1982; Sood & Tellis, 2005).

The emergence and birth of new industries is often based on existence at the interfaces of growth sectors in established clusters (e.g. Meristö, Kettunen & Hagström-Näsi, 2000) or technological discontinuities from outside the established industry (Afuah & Utterback, 1997). New industries can be started either by new firms or by established ones from other industries. A key variable seems to be whether an analogous product class with transferable competences exists when a new product class emerges. (Tushman & Anderson, 1986)

## *2.2 Technological discontinuities*

In Chapter 2.1, industry evolution and particularly the early phases of evolution were clarified. As the focus of this research is on technology and technological change, Chapter 2.2 concentrates on technological changes and discontinuities, which take place in the early phases of industry evolution. The explanation is based on understanding technology evolution in general as described by Abernathy & Utterback (1978) and Tushman & Anderson (1986). Thereafter, background will be built for considering technological discontinuities relating to path-dependency and changes in technology trajectories.

### 2.1.1 Technology cycles

Our current understanding of technological evolution is framed by the idea of technology cycles (Abernathy & Utterback, 1978). These development cycles can contain long periods of gradual evolution, technological discontinuities, as well as dominant design formation, and different phases of market evolution are usually characterized by different market structures and different patterns of innovation (Afuah & Utterback, 1997; Munir & Phillips, 2002). The model details the dynamic processes that take place within an industry during the evolution of a technology. According to the model (Figure 8), **technology cycles are composed of technological discontinuities** that trigger periods of technological and competitive ferment, when there is a lot of product and market uncertainty among the producers and the customers may not know what they want from the product. The early phases of technology evolution can be quite slow, for example Daim & Suntharasaj (2009) notice in their study of technology diffusion that both in barcode and RFID technology it took 25 years from its invention to its first adoption (Daim & Suntharasaj, 2009). Over time evolution enters a new era of standardization, during which market needs and product design features take place and a **dominant design emerges**. Dominant design formation is typically seen **as defining new technological eras**. After the appearance of a dominant design, product innovation becomes more incremental, focusing on refining the existing design and greater investment is devoted to improving the production process of the product (Abernathy & Utterback, 1978; Utterback, 1996; Anderson & Tushman, 1991). The pattern described repeats itself when a new technology with the potential to render the old one non-competitive is introduced, often **by a competitor from outside the established industry** (Afuah & Utterback, 1997). This results in a discontinuity, moving the innovation cycle back to the next substitute design and then triggers the next wave of technological variation, selection, and retention (Afuah & Utterback, 1997; Munir & Phillips, 2002). After **competence-destroying discontinuities, various trajectories open** up along with technological evolution in the industry. These include **innovations based on existing technologies, designs based on new technologies, and quite**

**often, hybrid technologies that promise to link the strengths of an established technology with the promised benefits of a new technology** (Munir & Phillips, 2002). It has been argued that revolutions usually come from outside the industry and a large corporation seldom provides its staff with incentives to introduce a development of radical importance; thus, these **changes tend to come from new entrants**.

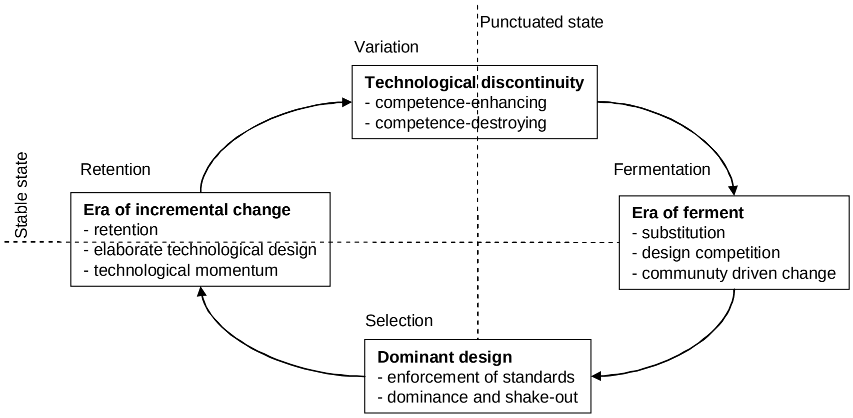


**Figure 8:** Dynamics of technological change (Anderson & Tushman, 1991; Hacklin, 2008)

The central proposition of **punctuated equilibrium** embodies three concepts: stasis, punctuation and dominant relative frequency (Gould & Eldridge, 1993). Stasis refers to a long period of relatively unchanged condition, punctuation is a radical change over a short time, and dominant relative frequency is the rate these events occur in a particular situation. The introduction of a disruptive, or competence-destroying, innovation (Tushman & Anderson, 1986; Lyytinen & Rose, 2003) can be considered a punctuation that interrupts the existing stasis, destroying the existing deep structure. One of the **key punctuations** is a major environmental change caused by technological convergence during which a technological discontinuity triggers a period of instability, which is closed by the emergence of a dominant design or business paradigm.

### 2.2.2 The effects of technological discontinuities

Much has been written in recent management literature about disruption and its impact on the market. Disruptions are typically associated with technological discontinuities and have been normally viewed as a threat to **industry incumbents** (Christensen, 1997; Tidd el al., 2001; Tushman, 1997). Some other researchers (e.g. Moore, 2007) have argued that disruptive innovation is more about **new opportunities** than about destruction. Disruption can be a major source of new business growth in the economy, whether it concerns an incumbent or a new entrant who learns to play by new rules. Historical evidence suggests that entrants find the biggest advantage when innovations disrupt the established trajectories of technological progress, a circumstance associated with moves to new value networks. The incumbent's disadvantage seems to be associated with an inability to change strategies, not technologies. (Rosenbloom & Christensen, 1998) For established organizations the challenge is to develop capability to manage these both kinds of innovations, i.e. "do better" (a steady state innovation process) and "do different" (a discontinuous innovation process) (Tidd et al., 2005). Birchal & Tovstiga (2005) name these different innovation processes as *institutional innovation* ("perfecting the known") and *revolutional innovation* ("imperfectly seizing the unknown") and call this capability to manage both kinds of innovations as *evolutional innovation capability*. When thinking about managing innovation, real challenges are dealing with it under discontinuous conditions and as an inter-organizational networked phenomenon.

Technological discontinuities, such as the microprocessor and cellular phones, have **reshaped the existing industries** in dramatic ways to create entirely new industries. The significance of a technological discontinuity is enormous as these advancements often destroy prevailing innovation patterns and threaten to render existing capabilities useless. The examples of technological discontinuities are often referred to as the **Schumpeterian process of "creative destruction"**. According to Schumpeter, the evolution of industries can be characterized as an endogenic process of creative destruction. A major issue in the works of Schumpeter was the question of what kinds of firms invent new technologies and generate new industries. (Lovio, 1993; Rothaermel, 2000) When evaluating potential discontinuities, the impact on the nature of competition and firm performance, it is important to consider whether they **would enhance or destroy fundamental competences** in the industry. Anderson & Tushman (1991) label discontinuities as *competence-destroying* and *competence-enhancing* changes of a more incremental type. Typically in the case of competence-destroying product discontinuities, **newcomers** have a chance to pioneer in the emerging industry. A classic example of creative destruction is the change from **vacuum tube production to transistors** when none of the industry leaders were able to successfully adapt to transistors. Typically in periods of market equilibrium, established firms earn economic profit based on innovative products or processes. This equilibrium is transient since they are **punctuated by discontinuities** in which prevailing competences are made obsolete and new competences will command economic rents for innovating firms. Tripsas (1997) demonstrates in her historical analysis how the typesetter industry has undergone three waves of "creative destruction" where competence-destroying, architectural change transformed the industry (Tripsas, 1997).

The literature presents two contrasting perspectives on the process of creative destruction: Schumpeter's seminal works that identify the small entrepreneur (1934) and then big business (1942) as the major source of innovation. Following the tradition of young Schumpeter (1934) he emphasized the role of individual entrepreneurs and new firms for most innovation. A central question regarding Schumpeterian competition is whether, through mechanisms like these, competition has a tendency to self-destruct and give way to long-lasting monopolies. When the ultimate dynamic change force comes from outside the industry, as in the case in which change comes from the external development of science, or innovations by equipment suppliers, the function of R&D within an industry is essentially to identify new opportunities and to adapt to and commercialize them. **In Schumpeterian competition it is inherently uncertain who will succeed in the commercialization of the innovation.** In a contrary case, **technological change is cumulative** at the firm level in the sense that efforts to advance technology today are built from the firm achieved yesterday. In this case the tendency for a dominant firm to emerge and continue to dominate was enhanced when technological advance was cumulative. (Schumpeter, 1975)

Still, the relationship of firm size and innovation is poorly understood (e.g. King et al., 2003). It has often been stated that new small firms are very important in the start-up period of new industries, and during the maturation process of the industry the advantages of new small firms tend to decrease and therefore old large corporations will achieve dominant positions. Collaboration between large and small companies has been a response to discontinuous technological change in high-technology industries. (Sadowski et al., 2003) The incumbents' path dependency provides entry for entrepreneurial companies that challenge the market position of established firms in the industry. This argument lies at the heart of the Schumpeterian model of innovation related to small firm growth. As already mentioned Schumpeter later furthermore proposed that incumbency might also create advantages due to sheer market size and existing resources of research and development. (Schumpeter, 1975) The latter model of innovation has been related to the growth of large firms. The dichotomy between the effects of different types of companies on innovative progress (industry evolution) has been widely discussed in the literature for decades (e.g. Nelson & Winter, 1982; Sood & Tellis, 2005). Firm size may be a critical determinant in choosing an innovation mode. It is plausible to assume that small and large firms possess complementary resources that are uniquely suited to facilitating the innovation process. Still, how the resources of small and large firms are combined in collaborative innovation within and between industries is a matter that has not received extensive treatment in the literature. The significance of **inter-organizational complementarities** is high especially in the case of converging technologies and industries.

Foster (1986) favors the Schumpeterian notion of competition driven by creative destruction. Foster defines technological discontinuities as periods of change from one group of products or processes to another. There is a break between S-curves, and a new one begins to form. His thesis is that technological discontinuities will not only arrive with increasing frequency, but that during these times of discontinuous change the attackers' offense will have the advantage over the defense.

In order to study the nature of competition following a technological discontinuity or technological convergence, it is important to distinguish between the technological and non-technological value chain activities of firms (Pavitt, 1998; Rotharmel, 2001). The combined effect of a discontinuity of a firm's technological and non-technological value chain activities will influence the incumbent firm's behavior. A firm exposed to technological discontinuity must assemble technological and non-technological assets to commercialize a technological breakthrough successfully (Pavitt, 1998).

It has been argued that incumbents are not likely to be threatened when new technology is competence-enhancing – drawing on the skills and capabilities developed previously – but threatened when it is competence-destroying (Tushman & Anderson, 1986). Tushman & Anderson (1986) express the idea that incumbents are in a position to benefit from innovation in their treatment of competence-enhancing technological discontinuities. The authors define technological discontinuities as offering sharp price/performance improvements over existing technologies, and define technological discontinuities with respect to impact on price and performance. They categorize technological discontinuities into competence-destroying and competence-enhancing. Competence-destroying discontinuities "require new skills, abilities, and knowledge in both development and production of the product" whereas competence-enhancing discontinuities "are order-of-magnitude improvements in price/performance that build on existing know how within a product class (Tushman & Anderson; 1986, 442). Such innovations substitute for older technologies, yet do not render obsolete the skills required to master the old technologies." A basic hypothesis is that competence-destroying discontinuities favor new entrants over incumbents. The framework developed by Tushman & Anderson (1986) is unable to make any firm-specific predictions, because their approach does not consider firms' different performance.

### 2.2.3 Complementary assets and technological change

Teece (1986) emphasizes the role of complementary assets necessary to commercialize the new technology. Teece uses the label *complementary assets* to describe factors, such as specialized manufacturing capability, access to distribution channels, service networks, and complementary technologies. Teece distinguishes between **generic, specialized, and co-specialized complementary assets** (Figure 9). Generic assets are general purpose assets which do not need to be tailored to the innovation in question. Specialized assets are those in which there is unilateral dependence between the innovation and the complementary asset. Co-specialized assets are those for which there is bilateral dependence. (Teece, 1986). Specialized complementary assets are built over long periods of time, and thus are path dependent and often idiosyncratic (Teece, 1997). Teece highlighted the importance of complementary assets as a critical factor that benefits from the innovation. The emerging new business opportunities at the interface of distinct industries can also offer promising avenues for value creation and creative cooperation (Rothaermel, 2001) for both industry sectors because of their complementary resources and knowledge with respect to the emerging business sector.

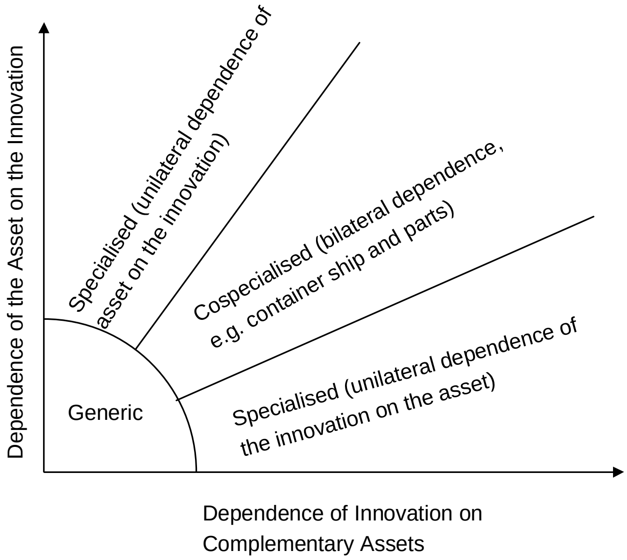


**Figure 9:** Dependence of innovation on complementary assets (Teece, 1986)

Teece (1986) argues that when incumbents possess critical *specialized* complementary assets, new entrants unable to contract for those assets may be at a disadvantage, despite their potential technological superiority. When incumbents control key specialized assets that are complementary to the new technology, they may be able to make advantageous deals to access the technology or, at least, to gain time to build own capabilities (Teece, 1986; Tripsas, 1997). Incumbents who focus too narrowly on the prevailing applications of a basic technology may leave niches open to which entrants can extend their technology and ultimately mount a broader threat (Christensen & Rosenbloom, 1995; Christensen, 1997).

Tripsas (1997) analyzes three central questions in the performance of incumbents and new entrants in the face of competence-destroying technological change: 1) Investment in developing new technology (What factors drive the investment behavior of incumbents and new entrants?); 2) Technical capabilities (How does the technical performance of incumbents compare to that of new entrants?); and 3) The ability to appropriate the benefits of technological innovation through specialized complementary assets. Rothaermel (2001) and Rothaermel & Hill (2005) focus their study on industry and firm-level performance implications of technological discontinuities that destroy the upstream competences of incumbents, but whose impact on the downstream competencies exhibits variation. Rothaermel & Hill, (2005; 54-55) propositions are:

> Proposition 1: ”Following a competence-destroying technological discontinuity, the performance of incumbent industry **declines** if the complementary assets needed to commercialise the new technology are **generic”** and

Proposition 2: Technological discontinuities and complementary assets: A longitudinal study of industry and firm performance. "Following a competence-destroying technological discontinuity, the performance of incumbent industry **improves**, if the complementary assets needed to commercialise the new technology are **specialised."**

They present hypothesized impacts of **absorptive capacity** and **strategic flexibility** on firm performance within the context of **creative destructive** and **creative cooperation** competition (Figure 10).

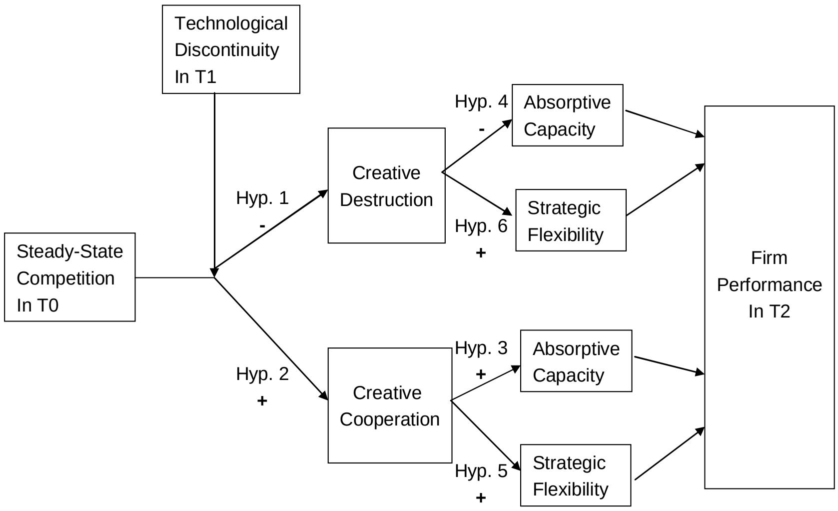


**Figure 10:** Creative destruction vs. creative cooperation (Rothaermel, 2001; Rothaermel & Hill, 2005)

The proposed nature of competition following a competence-destroying technological discontinuity is critically dependent on the value and appreciation of complementary assets. In the computer industry the classic example of creative destruction was the destruction of the mainframe computer industry, while new biotechnology has meant more creative cooperation with the pharmaceutical industry. (Rothaermel & Hill, 2005)

According to Tripsas (1997), three effects of technological change are key in understanding competition: the effect on 1) investment incentives, 2) technological competence, and 3) specialized complementary assets (Figure 11). In the typesetter industry from its inception 1886 through 1990 Tripsas argues that the industry has undergone three waves of creative destruction during which competence-destroying and architectural technological change transformed the industry. All three generations were competence-destroying, making the technological skills and routines of incumbents obsolete. Tripsas (1997) describes all new generations as incremental from an economic standpoint, and sustaining from a resource allocation perspective in that they appealed to existing customers. Only one of these three cases was an incumbent displaced by new entrants.

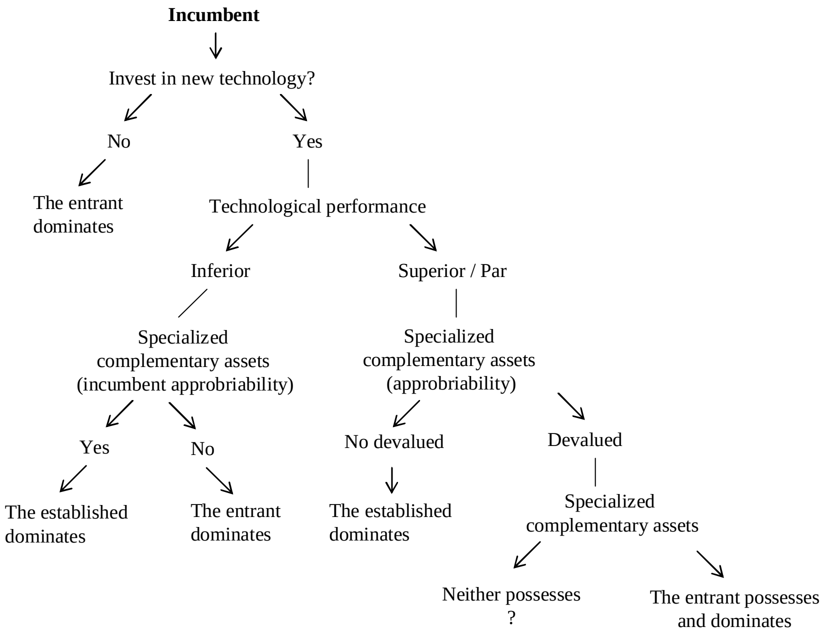


**Figure 11:** Performance in the face of radical technological change (Adapted from Tripsas, 1997)

In expanding the analysis beyond the Schumpeterian model of competition, the study demonstrates an established industry's complementary innovation role under discontinuous technological change. Complementary innovation destroys the existing industry structure, but instead of destroying the incumbent firms with it as in the Schumpeterian process, it may result in an industry structure of extensive cooperation between the incumbents and new entrant firms which allows symbiotic coexistence in a newly defined industry. The impact of complementary innovation on firm entry, inter-firm cooperation, firm performance, and the nature of competition might produce interesting new perspectives to analyzing the dynamics of emerging industries. At the moment, incumbent survival in the face of radical technological change has been explained by the persistence of market capabilities and complementary assets (Rothaermel, 2001; Tripsas, 1997). Inter-firm cooperation and strategic alliances with new entrants might provide chances not only to survive radical technological change, but also to boost the incumbent firm's performance in a newly defined industry.

## *2.3 Technological trajectories*

Since the introduction of the concept of *science-based sectors* by Pavitt (1984), extensive empirical work has been carried out by various scholars to refine this concept and to identify the underlying technologies that might characterize economic sectors as science-based. The results of many studies have revealed that sectors and technologies differ greatly in terms of the knowledge base related to innovation.

According to the evolutionary theory, knowledge and technology are understood to be cumulative and path-dependent in nature (Dosi, 1982; Nelson & Winter, 1982; Dosi et al., 1998). Huge investments in production technology and the scale effects acquired by technology and by the concentration process are typical of the paper industry. Both technology and concentration are closely interlinked with the decisions made by the companies in the past, and the industry is highly path-dependent. Technological trajectories are thought to lie within a technological paradigm which defines sets of acceptable procedures, relevant problems, and specific knowledge related to problem solving. Most technological progress takes place within existing paradigms and only rarely does innovation occur that leads to a paradigm shift. Incumbents in the industry are often unable or have problems in adapting to the new paradigm. (Dosi, 1982; Utterback, 1996; Graff, 2003). In the wireless communication technologies Kim et al. (2009) presents a technical framework for forecasting the commercialisation timeline and provides insight on technology trajectories from 1G to 4G.

Our understanding of the technology and its evolution is mainly based on the ideas of evolutionary economics, including different types of innovations, incremental and radical ones, and punctuated cyclical evolution of technologies. The knowledge and technology are understood to be cumulative and path-dependent by nature. The development of knowledge and technology in industries and individual firms follows a trajectory, i.e. a technology path. The main technology trajectories form the base of industrial branches on the country and industry level (Pavitt et al., 1989). Technological trajectories and industry evolution provide the theoretical background and approaches to evaluate the dynamics between traditional and emerging technologies and industries. The literature on evolutionary economics posits that innovations are history-dependent: i.e. organizations often search for new capabilities in areas that allow them to build on their established technological base. The central assumption in evolutionary theory is that of **local search**, where a firm's R&D activity is closely related to its previous R&D activity (Nelson and Winter, 1982; Lee, 2003). Local search mainly generates incremental innovations concentrated on existing technological domains. Consistent with local search, the concept of **absorptive capacity** suggests that a firm's ability to assimilate new technological knowledge is strongly associated with its past R&D activity (Cohen and Levinthal, 1990). Constrained search behavior may enhance the building of a firm's core competence (Prahalad and Hamel, 1990), whereas on the other hand such myopic approach may lead to the development of core rigidities (Leonard-Barton, 1992). By path-dependent evolution, knowledge and technology form technology trajectories. Once a trajectory is established, it may be difficult for an organization to switch to a development path that lies outside this trajectory. Technological trajectory is thought to adopt a particular technological paradigm, i.e. conduct, which defines sets of acceptable procedures, relevant problems, and specific knowledge related to problem solving. (Dosi, 1982) Competitiveness, therefore, is at least partly the result of an actor's capacity to create but also to trace, to absorb and to assimilate new technological and scientific evolutions. Scientific research, and more specifically scientific basic research, is a major dimension of this capacity to absorb and to internalize new knowledge (Verbeek et al., 2003).

Most technological progress takes place within existing paradigms and only rarely does innovation occur that leads to a paradigm shift. If the paradigm shift occurs in technology evolution, it means a start or divergence of a new technology trajectory. **In the case that existing technology trajectories merge and thereby combine their technological ingredients, we can speak about technology convergence.** It probably also leads to the reconfiguration of strategic and operative conducts of the industry, i.e. a paradigm. Thus, existing theories on the economics of innovation suggest that basic exploratory research serves, with some probability, to create new problem solving paradigms which, if successful, initiate new technological trajectories (Graff, 2003).

**Established firms** that wish to enter an emerging product market in which they have not participated must develop new capabilities that meet the demands of the market. The management of research and development, however, challenges decision-makers to perform in the context of uncertain environments in which competitors' actions are particularly difficult to anticipate (Tushman & Rosenkopf, 1992; Lee, 2003). The results of past searches become a natural starting point to initiate new searches (Nelson & Winter, 1982). At the individual level, decision-makers are bounded rational, so they cannot consider all possible applications and technological opportunities.

As a consequence of the fact that learning is typically incremental, learning processes tend to be path-dependent, and moving from one path of learning to another is usually very difficult and sometimes impossible. As a result, companies have difficulties to move to other paths, even though this may be possible, for example, through alliances, and mergers and acquisitions, especially when firms belong to related or converging industries. (Tidd et al., 2005)

# 3 FRAMEWORK FOR ANALYZING CONVERGENCE

This thesis focuses on technological convergence and especially the features in technological convergence that can be measured with the help of patent research. Having elaborated on the definitions and types of convergence, the chapter focuses on the stages of convergence and ends with a framework for analyzing the phenomenon of convergence.

## *3.1 Definitions and types of convergence*

The literature presents a multitude of definitions for convergence (Lei, 2000; Choi & Välikangas, 2001; Bally, 2005) while some authors (e.g. Yoffie, 1996; Wirtz, 2001; Bores et al., 2003) limit their definitions to the developments in the ICT industries. Many of the definitions of convergence are based on the idea of blurring industry boundaries and growing overlaps in technologies and services. The emerging new industry segment will either replace the former segments or complement them at their intersection (Dowling et al., 1998; Bröring et al., 2008). Convergent developments create opportunities and challenges for firms. However, confusion in the concepts and definitions has complicated the theoretical and empirical analysis of this widely used, but rarely properly defined term. Definitions and taxonomies are important because the meaning of convergence usually depends on the author and the implications of different types of convergence are very different.

Since Rosenberg's (1963) study on the early evolution of the US machine tool industry, the term *convergence* has been used in various industry settings with multiple definitions. Rosenberg termed this process **technological convergence** because different industries began increasingly to rely on the same set of technological skills in their production processes. In many studies, industry convergence is equaled with technological convergence. However, there should be a clear distinction between technology and industry convergence. According to Nyström (2008), the terms are strongly related, but they are still not interchangeable, because the forces driving technological convergence may not be the same as the forces driving the convergence of industries of product markets. **Stieglitz's (2003) framework** for analyzing convergence has been quite often used in convergence studies. The framework has some major drawbacks (the time dimension and archetypes hard-to-find in practice). In practice, complementary and substituting convergence often happen simultaneously and the effects can be asymmetric with different industry actors. In the convergence studies, this has been problematic especially in the case of product convergence. For example, buying a CD or downloading it from the Internet became interchangeable from the consumer perspective. This case of Internet services has been defined in some studies as complementary product convergence, such as online **music distribution and photo sharing** (Rikkiev & Seppänen, 2008). From the point of view of mobile network operators, telecommunication equipment manufacturers, and Internet service providers these really seem to be complementary. However, from the perspective of the music or the film industry there seems to be product substitution convergence. The Stieglitz (2003) framework has its problems in defining the type of product convergence, and one has to be very careful in defining the perspective taken in the analysis. For example, the literature has defined mobile phones with a camera and MP3 music player at the same time as product substitution and convergence of complements. Hacklin (2008) defines that **convergence in complements** occurs when previously unrelated products due to some technological change can be used together to create higher utility to consumers or bundled into new types of products with added value to the end user, e.g. **integrating camera or music player applications** in handheld mobile devices or smart phones provides an example of this type of convergence. In complementary convergence with products, different, but related needs are met by bundling products together.

Curran et al. (2010) distinguish the difference with processes of ***convergence*** **and** ***fusion***. In their classification "convergence describes a process, where objects move or stretch further from their prior and discrete spots, to a new and common place" and "fusion describes a process, where objects begin to merge with each other in the very same place of at least one of the objects" (Curran & Leker, 2010, 258). In other words, convergence means that distinct industries are merging in a new field providing opportunities for new inventions for distinct industry sectors. In fusing industries (e.g. the camera and mobile phone industry), the new segment will at least partly substitute prior business segments. For Hacklin (2008) convergence mainly represents transformation from two or more previously distinct industrial domains to a new, conglomerate area, which from the managerial perspective represents more than solely the sum of its parts. However, as mentioned, Curran & Leker (2010) see that there is a clear difference between the terms **convergence** and **industry fusion**, which have so far been used interchangeably. However, as both the substitution and complementary effects unfold in parallel and are often interlinked, it can be in practice very challenging to predict the overall effect of convergence (Greenstein & Khanna, 1997).

All in all, convergence across technologies, product markets or industries may be substitution-based (horizontal convergence) or integration-based (complementary convergence). In **substitution-based convergence**, the emerging new business sector will replace the former segments. The key strategic impact of convergence is that it drives companies with traditionally distinct and stable business models to the same territory. **Integration-based convergence** will complement them at their intersection. In other words, convergence in substitutes occurs when the effect of the phenomenon causes redundancy and obsolescence between previously distinct domains. In the case of complementary convergence, the synergy effects and results of two previously distinct fields coming together are more than the sum of their parts. (Dowling et al., 1998) Both forms may refer to core assets (e.g. patents, know-how, products), or to core activities (e.g. purchasing, operations, distribution, marketing) (McGahan, 2004). Following the framework, we can distinguish between six different categories of convergence (Figure 12).

| | | **Substitution processes** | **Complementary integration** |
|---|---|---|---|
| **Assets** | Convergence of technologies | Technology substitution | Technology integration |
| | Convergence of products | Product substitution | Product integration |
| **Activities** | Convergence of<br>• Marketing<br>• Sales<br>• Distribution<br>• Etc. | Activity substitution | Activity integration |

**Figure 12**: Types of technology, product or industry convergence (Christensen, 2011)

The output of the process of convergence, reduction of the differences between industries, can occur in varying degrees. Weaver (2007) describes "loose convergence" as the partial overlap and "deep convergence" as the full elimination of differences and thus the fusion of formerly separate sectors. Convergence changes the basis of competitive advantage, and firms must adapt their strategies depending on the nature (substitution/complementary) and degree of convergence (loose convergence/full convergence).

**Implications of convergence**

The significance of converging in the technological and market environment has been enormous as forming new rules about competitive environments reaches beyond formerly established industry boundaries. However, the literature presents contradictory conceptions on the effects of the convergence phenomenon (Hacklin, 2008). The competition between established industry actors and new entrants may lead to an explosive growth of new market entrants, or convergence may consolidate the markets. The literature indicates that vertical disintegration and value chain deconstruction are phenomena associated with convergence (Rosenberg, 1963; Pavitt, 2002; Brusoni & Pavitt, 2003), whereas true opposite characteristics have been reported in the literature as well, arguing that convergence is promoting a trend towards consolidation, vertically integrated companies and alliances (Wirtz, 2001; Yoffie, 1996).

Lei (2000) introduce a framework for examining the impact of technological convergence on the corporate strategies of a selected group of firms. He focuses on two distinct perspectives in investigating the impact: an industry evolution perspective that analyzes the effects of convergence on industry structure and boundaries, and a firm-based, competence development perspective that considers how technological convergence potentially redefines the firm's capability to learn and develop new sources of competitive advantage (Lei, 2000). On an industry level, convergence seems to predominantly cause structural changes and alter the competitive rules of industries (Porter, 1985). This leads to creative destruction or to a process of creative accumulation based on the emergence of complementary offerings across industries which are largely influenced by sectoral systems of innovations (Nelson & Winter, 1982; Malerba, 2005; Wonglimpiyarat, 2007). Eventually, the phenomenon can cause the appearance of an entirely new industry (Hacklin, 2008; Karvonen et al., 2008).

Many case studies have considered the old strategic controversy about the conditions under which firms should vertically integrate or consider some alternative, such as joint ventures or strategic alliances. Afuah (2001) argues that following a technological change that is competence-destroying to a firm and its suppliers, the firm's performance depends on whether it has been vertically integrated into the old technology or whether it is vertically integrated into the new one. Technology can be developed in-house or it can be acquired on the market, and between these two extremes there are several options open to the company. Companies may conduct R&D together with a partner, license in technology or use other forms of cooperation. Internal development is costly but often necessary to achieve the required technological base. Cooperative strategies involve less capital and are particularly suited to monitor new technological developments. Duysteers & Hagedoorn (1998) point out that the use of alliances often appears only effective in combination with internal development. Due to the overlap of industries, firms are faced with different bodies of knowledge owned in different sectors. The more industries overlap, the more firms in the new segment possess complementary competencies. This complementary knowledge could be learned through inter-industry collaboration (Bröring & Cloutier, 2008) and effective product development typically involves the participation of cross-functional teams that bring together different sources of expertise. It has been argued that one effect of convergence is the growing number of collaborative relationships and increased reliance on corporate networks and strategic alliances (Bierly & Chakrabarti; 1996; Stieglitz, 2002; Rikkiev & Seppänen, 2008).

For strategy analysis Berman & Hagan (2006) present technology-driven business strategy making technology an input to the strategy process rather than an enabler. Truly innovative ideas allow market insight and technological know-how to intersect. The focus in this technology-driven business strategy shifts to include exploration of new potentially disruptive products and services that have no precedents, emerging market segments that no one else see. (Berman & Hagan, 2006) Understanding the power of technological interfaces to change long-held business assumptions, companies can better anticipate market changes and actively plan out how to disrupt businesses. In the Berman & Hagan (2006) framework technology becomes a catalyst at the very initial stages of strategic planning merging with market insight to produce truly innovative ideas. It is well-known that invention is not same as innovation. Technological capabilities are of little value without the market insight that determines their application. Companies that are quick to recognize the potential they call technology-driven business strategy and learn to master its principles can set the pace of innovation in the future industrial evolution and drive the new competitive agenda (Berman & Hagan, 2006).

## *3.2 Evolutionary stages of convergence*

Before introducing the evolutionary stages of convergence, a more fundamental question arises: to what extent can these exogenous dynamics be associated with sequential phases of convergence (Hacklin et al., 2010), and does there exist such a thing as a convergence process? Theories of technical change have generally been classified into two broad categories, namely, *demand-pull* and *technology-push* theories. The former defines market forces as the main determinants of technical change (demand-pull theories) and the latter sees technology as an autonomous factor, at least in the short run (technology-push theories). **The linear model** of the technology-push theory projects the progression of basic scientific knowledge through applied research of product development to commercial products. Dosi (1982) notes that the demand-pull approach fails to produce sufficient evidence that ”needs expressed through market signaling“ are the prime movers of innovative activity. Dosi (1982) is trying to introduce a bridge between the demand-pull and technology-push theories. Dosi (1982) also states that market induced factors relate much more to normal technology than to **discontinuous innovation**.

Such a clear cut distinction between push and pull is hard to make in practice. In the definitions of convergence, technology convergence cannot be described as a technology-push pattern and product convergence as the market-pull model. However, in most cases technological convergence is a precondition to product convergence. The phenomenon of convergence may be technology driven or needs driven, but the most influential are those that merge the two perspectives. The main problem underlying this crude push vs. pull distinction is that business planning and technology planning are isolated from one other. The relative importance of technology-push seems to be more important in the early phases of convergence and market-pull in the later phases of convergence.

The evolutionary phases of the convergence process (Narin et al., 1997; Hacklin et al., 2009) have led to a discussion on the stage model of inter-industry innovations. Hacklin et al. (2009) identify, describe and formalize four different stages of the convergence process: 1) knowledge convergence, 2) technological convergence, 3) applicational convergence, and 4) industrial convergence. Even though the relationships between science, technology, and industry are very complicated, the stages provide a starting point from which to understand how science and technology, the technology industry, and further science, technology, and industry are related to each other in convergent industry environments.

***Science convergence***

The evolutionary phases of convergence start from scientific disciplines, during which distinct disciplines are beginning to cite each other and eventually develop toward closer research collaboration (Hacklin et al., 2009). One can regard the process of convergence as being ignited by the erosion of boundaries that define industry-specific knowledge (Pennings & Puranam, 2001). Hence, the trajectories of knowledge bases come closer and spill-over effects give rise to innovative activities. According to Hacklin et al. (2008), such erosion of knowledge boundaries does not take place, but rather industries develop in the longer term. This is likely to be based on the awareness of combining one’s own internal knowledge base with an external one in order to create something novel. Hacklin et al., (2009, 725) defines the stage of science convergence: “Knowledge convergence denotes the emergence of serendipitous co-evolutionary spill-over between previously unassociated and distinct knowledge bases, giving rise to the erosion of established boundaries that isolate industry-specific knowledge."

Potential indicators of convergence in science are co-authorships and co-citations in scientific articles, journal topics (Curran & Leker, 2010), and references to non-patent literature (NPL) in patent documents (Karvonen & Kässi, 2011). Many indicators of scientific or technological development focus on either scientific or technological activity. The interdependencies and interactions between science and technology have been measured in many studies with the use of different empirical indicators. Mayer (2000) founds three basic approaches in studies on science-technology interaction: industrial scientific research publications, university patenting and non-patent literature (NPL) citations. The most straightforward use of an indicator at the company level is the average number of science references cited on the front page of the company's patents. Strong science linkages indicate that a company is building its technology on advances in science (closeness to science). High-technology companies tend to have more science linkages than their competitors, and science linkages have been found to be predictive of a company's stock market performance (Nagaoka, 2007). If the sources of NPL citations are scientific, they provide the opportunity to systematically examine relationships between science and technological development (Callaert et al., 2006), as well as the possible changes in science trajectories.

Non-patent literature (NPL) references not only consist of scientific articles, but also include a mixed set of other types of publications: conference proceedings, books, and many other non-scientific sources such as disclosure bulletins, abstract services, and so forth. In practice, patent applications that have a closer link to the traditional fields of science, for example, chemistry and physics are more frequently confronted with non-patent literature (Meyer, 2000). According to OECD patent statistic manual (2009), references to non-scientific documents such as patent abstracts and commercial online patent database services should be removed for the purposes of analyzing the science linkage in patents. Karvonen & Kässi (2011) divided NPL citations into scientific and technology-related categories (Table 1).

**Table 1:** Taxonomy of NPL reference types (Adapted from Callaert et al., 2006)

| **Category** | **Sub-category** | **Description** |
|---|---|---|
| Science "at large" | SCI-covered journals | References to scientific publications published in serial journal literature covered by the Science Citation Index (SCI). |
| | Not SCI-covered journals | References to scientific publications published in serial journal literature but NOT covered by the SCI. |
| | Conference proceedings | Proceedings from conferences and workshops. |
| | Books (reference books, databases) | All books (including encyclopaedias, handbooks) |
| Technology "at large" | Industry/company-related documents | Technical Disclosure journals and bulletins; Company journals: catalogs, brochures; technical reports |
| | Patent related-documents | Patent abstracts; abstract services, search reports |

In the taxonomy of reference types (Table 1), in a most narrow sense only journal references refer to the actual scientific journal literature and covered by the Science Citation Index (SCI) could be considered scientific. However, other serial journal literature, conference proceedings, and books can be considered "science at large." On the other side, industry and patent-related documents can be seen as "technology at large." (Callaert et al., 2006) One indicator of interdisciplinary development is the percentage of citations outside one's own industry discipline.

***Technological convergence***

By definition, the converging of technologies is based on blurring industry boundaries between distinct industries. This definition implies that overlaps between technologies are a precondition for the phenomenon. Hacklin (2008) argues that as knowledge bases eventually translate into technologies, this phenomenon, in turn, does not necessarily represent the result of any conscious managerial action, but can in many cases be regarded as a rather autonomous process, which takes place beyond the firm level. It is as a consequence of the coming-together of underlying trajectories that new opportunities emerge, allowing firms to cross-fertilize throughout the technological intersection, and making technologies pervade new products. As the underlying trajectories converge, the involved technologies intersect in a way that a common technological knowledge base emerges, allowing opportunities for higher performance through diversification into new areas within the underlying industries. (Hacklin et al., 2009; Duysteers & Hagedoorn, 1999) Innovations at this stage are at least partly based on a technological intersection, where coming together of technologies has created tangible potential for the creation of new applications. Hacklin et al., (2009, 726) defines the stage of technological convergence: "Technological convergence denotes the transition of knowledge convergence into a potential for technological innovation, allowing inter-industry knowledge spill-overs to facilitate new technological combinations."

Potential measures for technology convergence are co-inventions, growing overlaps and co-classification in Standard Industrial Classification (SIC) and International Patent Classification (IPC) codes, and knowledge spill-overs found in patent citations. Patent data have been mainly used as an indicator of technology convergence, as patents are the easiest way to monitor convergence – implying that the considered industries have a significant propensity to protect new technological developments by patents (Preschitschek et al., 2011). This study provides new insights into the analysis of technological convergence by utilizing **patent citation data** in the analysis.

The interdependencies and interaction between technology markets and product markets have been under wide discussion because of the fundamental difference between them, and it has been widely recognized that changes in technological leadership do not necessarily need to result in changes in market leadership (Gans & Stern, 2003). In order to evaluate analytically the competitive and complementary effects of technological convergence, one challenging methodological problem is with the interaction of technology (patents) and product markets. The patent literature does not contain a reliable method to map patents into product markets (Harhoff et al., 2007).

***Applicational and industrial convergence***

Technology convergence may trigger market convergence with new product/market combinations. Once the opportunity for the creation of new applications arises, the trajectory of technological change becomes dependent on the industry's ability to build upon the technological intersection. According to Hacklin et al. (2010), this step of technological integration does not only result in the convergence of new applications, products or services, but also on a more generic level, leads to service or applicational convergence, as new, higher level forms of providing value for the customer and differentiation towards competitors emerge (Edelmann et al., 2006). Hacklin et al., (2009, 727) defines the stage: "Applicational convergence denotes the transition of technological convergence into opportunities for new value creation in such a way, that it with respect to the majority of metrics outperforms the sum of the original parts."

As emerging applications evolve, they increasingly infringe the original value-creating territories of underlying sectors or industries and might lead to a collision of business models, as the development gradually removes the sectoral boundaries between the involved industry segments (Duysteers & Hagedoorn, 1999; Hacklin, 2008). In terms of competition, this paradigm shift changes the rules of the industry. In the "substitutive paradigm" the new industry segment will replace the former segments leading to competitive convergence. In the "cooperative paradigm" a new market emerges which requires the combination of resources and competencies from previously separate industries, e.g. through strategic alliances or other forms of collaboration, leading to complementary convergence. (Dowling et al., 1998) In the "coopetitive paradigm" convergence may also imply a need to collaborate and compete at the same time. Hacklin et al. (2009) provide an example of mobile handset manufacturers and software manufacturers, which can originally be regarded as highly unrelated. Today, however, there is direct competitive collision as industry convergence is bringing along the battle for mobile handset software platforms. Such a collision of previously established business models occurring within converging industries may be seen in alliances, and mergers and acquisitions reaching beyond previously established industry boundaries (Greenstein & Khanna, 1997). According to Hacklin et al., (2009, 728), "industrial convergence denotes the transition of applicational convergence into the shift of industry boundaries in such a way, that firms from previously distinct industries through the emergence of common applications suddenly become competitors." Hacklin (2008) is mainly concerned with the substitution type of convergence. However, the complementary or integration type of convergence also provides real opportunities for inter-industry collaboration. In addition, the forces driving the knowledge and technological convergence are usually not the same as the forces driving the convergence of product markets and industries; for example, there could be fierce competition in technologies, whereas in the later stages there are more incentives to cooperation.

Potential measures for product market and industrial convergence include changes in product portfolios, customer trends, strategic alliances, and mergers and acquisitions. The evolutionary stages of convergence (Hacklin, 2008) have led to a discussion over the stage model of inter-industry innovations, and Curran & Leker (2008; 2010) present some potential measures for monitoring the stages of convergence (Table 2). He & Fallah (2009) have utilised patent co-authorship data to construct inventor networks. In their study, the network actors are patent authors, and the organizational units are the patent assignees. Not surprisingly, professionals are more likely to move between companies in a same sector rather than crossing sectors. (He & Fallah, 2009)

**Table 2:** Measures for monitoring the stages of convergence (Adapted from Curran & Leker, 2010)

| ***Convergence in*** | ***Main sources*** | ***Measures*** | ***Possible data sources*** |
|---|---|---|---|
| Science areas | Scientific articles | - (Co)Authorships in scientific articles<br>- (Co)Citations<br>- Journal topics<br>- NPL citations | - SCI / SCOPUS<br>- SciFinder<br>- PATSTAT (NPL) |
| Technology | Patents | - Co-Invention (Assignees; Inventors)<br>- SIC and IPC co-classification<br>- Knowledge spill-overs (patent citation data) | - Patent offices<br>- SciFinder<br>- PATSTAT |
| Product markets | Press releases | - Product portfolios<br>- Customer trends | - Company data<br>- Expert interviews |
| Industry segments | General firm & industry information | - Product portfolios<br>- Strategic alliances<br>- Mergers and acquisitions | - Company data<br>- Factiva<br>- Newspaper archives |

Scientific, technological, and industrial knowledge differ greatly in the characteristics of their creation, and clarifying the linkage between them is not easy because the properties of knowledge generated in each stage are very different. In case of emerging technologies, where little or no historical data available, use of science and patent indicators have been used on forecasting and foresight studies. Bibliometrics and patent analysis are emerging methods used for forecasting technologies. They are used in forecasting technologies including RFID (Daim & Suntharasaj, 2009), data storage technologies (Daim et al., 2008), laptop batteries (Daim & Jordan, 2008), energy storage technologies (Harel & Daim; 2009) and nanotechnologies (Daim et al., 2007). Harel & Daim (2009) founded growth curves as a convenient method to forecast which technologies are developing more rapidly using the available patent and bibliometric data available. Daim et al. (2007) demonstrate that there is a strong correlation between research funding and different research outputs. In their study the time lag between funding and patents issued is evident from the patent trend analysis and bibliometric analysis. In case of nanoscope the patent time lag was found to be approximately five to six years, for journal article it was approximately two to three years and conference presentations happened right after the funding (Daim et al. 2007). The evolutionary stages provide a starting point to understand the complicated phenomenon and relations between science, technology, and industry evolution.

### 3.3 Framework for analyzing technological convergence

### 3.3.1 Linking science, technologies and industries

Data collection is the most critical issue when researching the convergence phenomenon by patent analysis methods. It is possible to do patent analysis both at the firm and industry (or national) level. One argument that may lead to choosing the more aggregated level is the existence of externalities at the firm level. If the patenting behavior of firms is not only a function of the firm's own R&D, but also of the R&D of competitors, then the model at the industry level could conceivably be a more precise instrument than estimates at the firm level. For science-based industries, the publications of the scientific community are important. However, these links are very loose and currently no concordance exists between science classifications and industrial sectors. (See Harhoff, 2006; Blind, 2006)

All in all, there is the problem of associating patent applications with industries. Several research teams have invested in generating concordance tables between Standard Industrial Classification (SIC) and International Patent Classification (IPC) (Evenson & Puttnam, 1988; Verspagen et al. 1994, Johnson, 2002; Schmoch, et al., 2003). However, the natural classification of patents by their IPC codes does not translate easily into some industry classification. Transition matrices to accomplish this transformation have been developed for some nations (e.g. Canada; see Evenson & Putnam; 1988) but not for a large number of European countries. Verspagen (1994) suggested a concordance scheme between the 4-digit level IPC sub-classes and 22 industrial classes, in which many of the 625 IPC sub-classes are linked with different weights to different sectors. The Johnson (2002) concordance table is based on data from the Canadian patent office where for 625 IPC sub-classes he defines probabilities of linkages to about 115 different sectors of manufacture and use. The concordance table by Schmoch et al. (2003) starts with the selection of industrial sectors at the 2-digit level and continues with a finer breakdown to the 44 sectors of manufacture. Industrial sectors are defined by the manufacturing characteristics of products, so that it is possible to associate them with technologies. On this basis, technical experts associated each of the 625 IPC sub-classes to one of the industrial sectors even if multiple linkages to other fields were obvious. In the case of complete equivalence between technologies and industries, all applications should appear as diagonal elements, even though in reality there is often a strong interconnection between different sectors (Figure 13). According to Blink (2006), the interconnection and the fact that large firms produce a broad spectrum of technologies are reflected in the concordance matrix frequently below 20 per cent. This means that in many cases, other sectors contribute more patents of a specific field than the related core sector itself (Blind, 2006).

| | Sector 1 | Sector 2 | Sector 3 | Total |
|---|---|---|---|---|
| Tech. 1 | 50 | | | 50 |
| Tech. 2 | | 30 | | 30 |
| Tech. 3 | | | 20 | 20 |
| Total | 50 | 30 | 20 | 100 |

| | Sector 1 | Sector 2 | Sector 3 | Total |
|---|---|---|---|---|
| Tech. 1 | 25 | 15 | 10 | 50 |
| Tech. 2 | 15 | 9 | 6 | 30 |
| Tech. 3 | 10 | 6 | 4 | 20 |
| Total | 50 | 30 | 20 | 100 |

| | Sector 1 | Sector 2 | Sector 3 | Total |
|---|---|---|---|---|
| Tech. 1 | 50 | | | 50 |
| Tech. 2 | 30 | | | 30 |
| Tech. 3 | 20 | | | 20 |
| Total | 100 | 0 | 0 | 100 |

**Figure 13:** The ideal, real and employed association matrix (Schmoch et al., 2003)

There are a number of challenges in associating technologies and industries. Schmoch et al. (2003) concluded that the correlations between these tables are generally low, and, according to Harhoff (2006), mapping IPC classes into industries is still largely *terra incognita*. From the perspective of industrial economics, the IPC itself is mostly taken as given because patents are considered as input indicators and not as outputs of the R&D system (Leydesdorff, 2008). Blind (2006) recognizes four main problems in establishing a link between technological and economic indicators with these concordances: 1) international comparability, 2) level of disaggregation, 3) strong empirical basis, and 4) easy applicability to specific problems. Regardless of all these challenges, the concordance tables can provide a powerful tool for analyzing the relationships between sectors and technologies and between technological and economic development.

IPC codes are a hierarchical way of assigning the category to which every patent belongs. There are 8 sections, 120 classes, 628 sub-classes and about 70,000 groups. In our analysis we have utilised a higher level classification, by which the 628 sub-classes are aggregated into 35 technological fields, and for descriptive purposes these are further aggregated into five main categories: Electrical engineering, Instruments, Chemistry, Mechanical engineering and Others. (WIPO, 2008)

### 3.3.2 Analyzing technological convergence

Patent data are the most straightforward way to monitor technological convergence. Patent information can provide an approximate description of the innovation activity occurring in most fields of technology in developed countries, and it is accepted as the only viable quantitative measure because it is accumulated over a long period of time (Trajtenberg, 1990; Ernst, 2003). Patent data offer a valuable data source as individuals and companies currently apply for patents on about 1 million inventions (patent families) each year. A uniform structure throughout the world and the long time series available makes the patent data a unique source of information. The large number of patent applications is not a completely new phenomenon: even in 1980 protection was being sought for more than 600,000 inventions per year worldwide and, since then, countries such as China and Korea have joined the race for technological innovation. (EPO, 2010) Empirical studies indicate that around 80% of all the information contained in patent documents cannot be found anywhere else in comparable detail. Patents and scientific literature can often be regarded as complements: patents focus on how to make inventions work, whereas scientific articles focus on the scientific contribution and research findings. As all patent applications are published 18 months after the priority date, patent data contain new information on a company's new product development activities which cannot be found elsewhere. In many cases the patent application is published before the corresponding academic paper.

The relatively new patent databases available have enhanced the opportunity to systematically retrieve data on a large scale. One of the most innovative initiatives is the European Patent Office (EPO) Worldwide Patent Statistical Database, also known as PATSTAT. The database covers data from over 80 countries including over 70 million records. The database is designed to serve statistical purposes and it is updated twice per year. Patent applications are classified by the applicant, inventor, priority dates, application date, and technological classes. (EPO, 2008) Researchers are increasingly using patent citation measures for technology management and policy analysis (Jaffe et al., 2000; Hall et al., 2001; Stuart & Podolny, 1996; Harhoff et al., 2007).

This study uses patent citation analysis in investigating the evolution of convergence. In this phase, patent analysis is utilized to assess four main issues: 1) competition between industry sectors and technologies, 2) knowledge accumulation in industry sectors and technology fields, 3) knowledge spill-overs and the beginning of new technologies or industry sectors, and 4) overlapping technological fields and industry sectors, i.e. convergence. The key objective of the whole study is to develop tools and measures, which are based on patent database information, and to observe and measure the above-mentioned dimensions in industry evolution. The research methods and measures are clarified in Chapter 4. When these dimensions are well understood and managed, it can be said that we are quite advanced in researching the convergence phenomenon.

# 4 RESEARCH METHODOLOGY

This chapter presents the empirical research context and research strategy, data collection methods, and evaluation of the research quality.

## *4.1 Research strategy*

Part II of this dissertation consists of eight research publications addressing the research sub-questions. The first publication identifies an emerging new industry sector. The second and third paper utilize both qualitative and quantitative approaches in order to provide insights into the future industry evolution. The other five papers consist of empirical analyses utilizing patent data analysis methods which have been applied to the one and same data material. The fourth one utilizes patent citations made and addresses the sub-questions related to the mechanism of spill-overs between the sectors and the rate of technological innovation in converging environments. A quantitative approach to analyze the dominance of emerging technologies is taken in the fifth publication, which utilizes e.g. citations received and pioneering innovations in the industry. The sixth paper continues the analysis of future competitive arena by gathering data from the most significant overlapping technology fields and provides insights into future value chain development. The seventh publication utilizes the citation analysis methods in order to provide insights into how patent citation data can be used to evaluate and anticipate technology convergence. A synthesis of patent citation methods in analyzing and anticipating technological convergence is drawn in the final publication.

The study utilizes both qualitative and quantitative research methods in order to enhance understanding of the complex phenomenon. The key research methods in this study include, first, a Delphi study that is complemented alliance activity data, second, interviews complemented with financial and patent data, and, third, patent citation analyses between the paper and electronics industries. The results of the financial analysis and themed interviews revealed that there is not yet an economic basis for industry convergence in the emerging industry sector. The patent analysis revealed that there is already evidence that in the future the core technological trajectories are becoming increasingly similar. Patent analysis could give us new insights related to the theories of convergence research. This kind of study that combines both qualitative and quantitative methods has been defined as a **mixed-method approach** (Dubois & Gadde, 2002). Triangulation in general means combining several research methodologies, data sources, or theories to examine the same phenomenon. The use of method, data, investigator, or theoretical triangulation potentially offers more valid and objective interpretations (e.g. Decrop, 2009). A multi-method research design was used because of the research results of earlier studies and because it provides different levels of data and different perspectives on the phenomenon. In other words, the idea was to systematically combine the theoretical framework, empirical fieldwork and case analysis (Figure 14) and build more on refining the existing theories than inventing a new one. One major difference with mixed-method approaches, as compared with both deductive and inductive studies, is the role of the **framework.** In studies relying on mixed methods, the original framework is successively modified, partly as a result of unanticipated empirical findings, but also of theoretical insights gained during the process. (Dubois & Gadde, 2002)

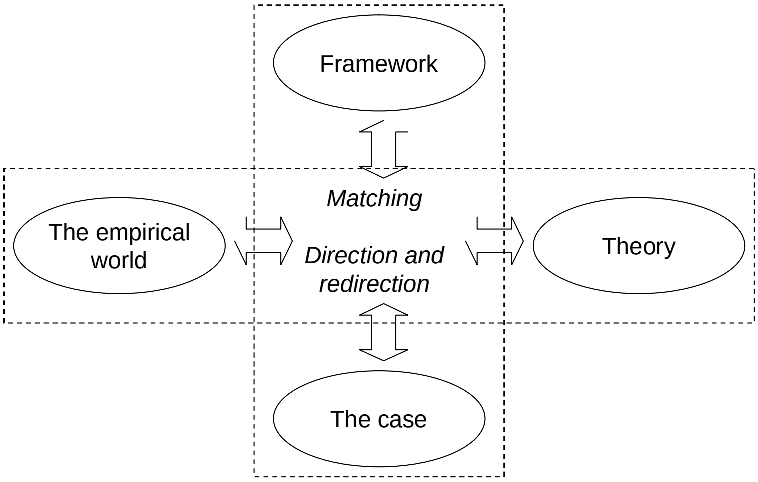


**Figure 14:** Systematic combining (Dubois & Gadde, 2002)

Two opposite philosophies traditionally applied to management research are positivism and phenomenology (Modell, 2009; Olkkonen, 1993). The positivist view on research relies on hypothetico-deductive reasoning from large data sets, whilst phenomenology begins from subjective interpretation and understanding of the studied phenomenon, and generalizations from rich data sets. Mixed-method research, combining qualitative and quantitative approaches, has recently attracted increasing attention (Dubois & Gadde, 2002; Modell, 2009). This research is grounded in the inductive (interpretative) research tradition, but does not rely on subjectivist methodology in producing research results. Theoretical frameworks were used to evaluate the empirical material in the research process. Thus, the research process represents the mixed-method approach in which movement between theory and practice (Figure 15) with earlier experiences and research findings provided the basis for the next research phase. (Modell, 2009; Järvensivu & Törnroos, 2010).

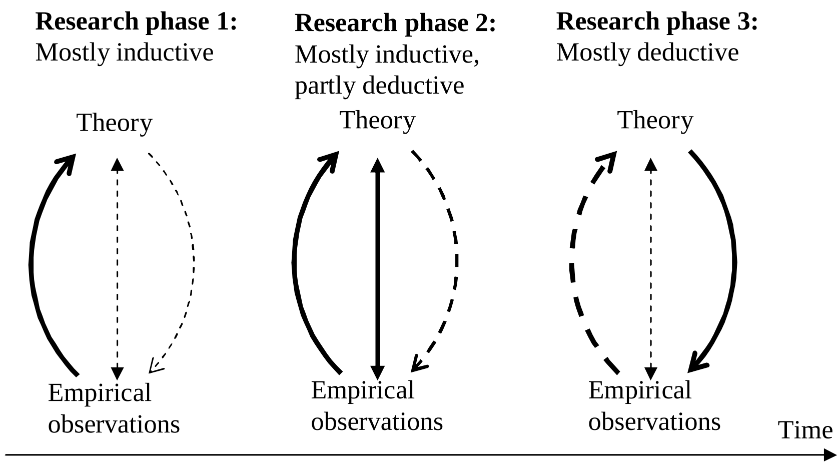


**Figure 15:** The research approach (see Järvensivu & Törnroos, 2010)

Debates in the philosophy of social science may not seem very relevant to most industrial engineering academics. However, whenever a research is carried out, researchers make assumptions about how the world is (ontology) and how we can come to know it (epistemology). In the continuum of ontological and epistemological views (Figure 16), naive realism relies on the positivistic research tradition in which only one true reality exists and it is possible to know exactly what that reality is. So, the aim of the research is to model the reality through objective empirical observation. In the other end, naive relativism sees that there are multiple viewpoints to the reality and truth. The aim of the research is to study knowledge and its creation processes. *Critical realist* and *moderate constructionist* approaches lie in the middle of the continuum. The critical realist approach originates from positivism where the truth is a matter of objective empirical observation and a consensus within a scientific audience. The moderate constructionist approach grounds its philosophy on phenomenology, which emphasizes subjective and multiple viewpoints to knowledge and truth. (Easton, 2002; Järvensivu & Törnroos, 2010)

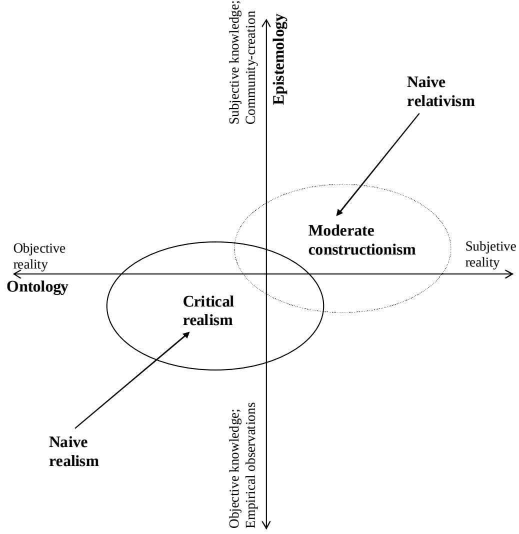


**Figure 16:** Ontological and epistemological dimensions of research approaches (Järvensivu & Törnroos, 2010)

The first research phase of this study was a mainly future-oriented explorative study in which it is difficult to gather objective knowledge following mainly the moderate constructionist approach. The second and third research phases move more to the critical realist approach. The methodology relied on patent analysis assuming that there is a more objective reality (ontology) and it is possible to move closer to local truths and the reality through objective empirical observations (epistemology) (Järvensivu & Törnroos, 2010).

## 4.2 Data collection and analyses

### 4.2.1 Opportunities for industry transformation

In addressing the first research sub-question, the research process began with an extensive literature review of technological discontinuities, dominant designs, industry life cycle theories, complementary innovations, as well as studies on business opportunities arising at the interface of distinct industries. The aim was to gain a theoretical pre-understanding of this phenomenon and provide insights into the transformation of traditional industries.

Technology foresight stems from Japan, when Nistep (National Institute of Science and Technology Policy) made the first foresight research in 1971. The results from its eighth research were published in spring 2005. Nistep has a long tradition in the use of the Delphi method in the foresight research. There are a variety of methods for forecasting the future impact of a product, process, or idea. Some use quantitative approaches to model the future, and others use qualitative methods that synthesize the experience and knowledge of experts, or even their personal intuition. Human behavior and technology adoption are both influenced by many factors, leading to unpredictable outcomes. Nevertheless, forecasts can provide insights into how things might unfold, which helps us to better manage the future. **The Delphi**

**method** was chosen as an empirical research tool for futures research and it has been used in several studies (e.g. Scott, 2000; Tapio, 2002; Padel & Midmore, 2005) and have been found an effective tool for analysing technology evolution (e.g. Karvonen, Ryynänen & Kässi, 2009). The definition of the approach can be found in the seminal work of Linstone and Turoff (1975, 3): "Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem." The characteristics of the Delphi technique are anonymity, iteration, feedback, and consensus (e.g. Kuusi, 2001). The Delphi method is intended to produce sound opinions and arguments, not statistically significant results. Okoli & Pawlowski (2004) have collected the main differences between a traditional survey and the Delphi method including differences related to the whole procedure, representativeness of the sample, sample size for statistical power and significant findings, individual vs. group response, reliability and response revision, construct validity, anonymity, non-response issues, attrition effects, and richness of data. While many Delphi studies are focused on purely forecasting issues, a Delphi variant, called Argument Delphi (Kuusi, 1999; 2006; Ryynänen et al., 2008), focuses on producing relevant arguments, and the idea is rather to obtain several well founded opinions, and even to find areas and viewpoints that the panelists disagree on. Panelists are informed about the names of other participants, but the responses are given anonymously.

According to Kuusi (1999; 2001), the main success factors in the Delphi process are the selection of the expert panel, anonymous argumentation of the expert panel, the success of making meaningful questions and future statements, structured and systematic evaluation of the statements including also other factors than probability, accumulation of relevant user-friendly future statements from diverse experts to the data banks, which are really to be used to support decision-making, and produced material relevance in strategic decision-making. The Delphi study is critically dependent on the quality of knowledge captured, which in turn depends on getting the right people to the process, and the way the process is facilitated. This study benefited from a wide range of opinions presenting both deep knowledge of printed functionality (specialist) and industry experts (generalists) as well as industry actor perspectives (industry).

A qualitative tool for improving foresight, the Delphi method, was used to explore the dynamics between mature and emerging new industries, technological discontinuities, and future business environment. Delphi uses expert feedback to refine an informed perspective on complex and uncertain issues. The purpose of the Delphi study was to create a holistic view of industry development, not only concentrating on technological trends, but also taking into account other factors, such as the market, customer behavior, social, and regulatory aspects, which can be important drivers of convergence.

The Delphi process concentrated on 1) printed functionality application areas (history and present situation, life cycle models, and economic importance), 2) threats and opportunities from the point of view of the Finnish industry (critical success factors, current vs. future competences, the dynamics between traditional and emerging industries, Finnish strengths and weaknesses), and 3) change drivers in the future (technological trends, market and customer trends, social and other trends, legal issues). The focus of the case study was in the demand trends between the printed and electronic media (printed/electronic media convergence), technology expansion opportunities through printed functionality (marriage of paper & electronics) and incumbents' changes to cope with emerging growth drivers and cooperation possibilities. The three-round Delphi yielded primary data and alliance activity secondary data. Empirical data related to the alliances between the industries were collected to review the past and current state of cooperation related to ICT and the PPI sector and especially to printed functionality. Ultimately, the goal of the paper was to provide insights into the renewal of traditional industries.

### 4.2.2 Industry convergence and technological trajectories

The results of the analysis of previous research revealed that the emerging business sector in the intersection of paper and electronics provides new business opportunities and potential for industry transformation. Therefore, the next step was to clarify the emerging phenomenon of convergence, different types of convergence and potential effects of industry convergence. The emerging business, the printed functionality sector, was in very early stages in its life cycle, and so the empirical focus was on the radio-frequency identification (RFID) value chain which is already a more mature business area. The analysis concentrated on 202 firms operating in the radio-frequency identification (RFID) value chain. Financial data collected from Thompson ONE Banker were available, however, only of 38 firms operating in the RFID value chain. Financial and patent data were collected from the upstream electronics, paper and printing, downstream electronics and vertically integrated electronics industry companies. Patent counts and International Patent Classification (IPC) analysis of the industries provided views to the trajectory change and convergence development between the industries.

The previous study was complemented in the third publication with 12 interviews and patent data from 84 companies operating in the RFID value chain in order to increase understanding of the technological trajectories of the industries and how industry convergence affects the evolution of the industries. The other goals of the paper were to analyze what kinds of key actors and value chains exist in the RFID industry and how printed functionality and RFID value chains might develop during the next ten years. Factors used in analyzing the performance differences in the value chain included both financial and non-financial factors. The purpose of the interviews was to provide future visions to the printed functionality and RFID value chain development from the perspective of the paper industry.

**Patent analysis**

A patent holder receives exclusivity that enables investment and higher returns on investment. Patents are considered strong and enforceable legal rights, which also makes an invention tradable for licensing. The disadvantages of patents are well-known. The patent reveals the invention to competitors after 18 months, it can be expensive, and patents are enforceable only after a grant process which can sometimes be long. In addition, not all innovations are patented by firms and the market value of patents is extremely skewed (e.g. Hall et al., 2005). Different technologies are differently patentable and firms may have different propensities to patent their innovations since in some industries patents have crucial strategic importance.

As an industry develops and matures, it becomes necessary to make sure that there are effective ways of appropriating returns on initial R&D investments so that the positive development will continue. Patents are one of the many appropriability mechanisms discussed by Levin et al. (1987), Cohen et al. (2000), Teece (2000) and Hurmelinna-Laukkanen (2009), for instance. Together with other mechanisms they help to define the boundaries of companies' intangible assets by limiting the use of patented inventions, copyrighted works, and the kind of technological and commercial information that is important for the company's business operations and which is kept secret (Soininen, 2007). Patents that provide their holders with the right to prevent others from utilizing their inventions (commercially) for a certain period may prove essential in building and maintaining competitive advantage, particularly when the company is technology-based and aims at technological leadership.

The innovative performance of organizations has been analyzed with indicators, such as research and development expenditures (R&D inputs), patents, patent citations and new product announcements (Hagedoorn & Cloodt, 2003). Patent documents can be a source of rich information about technical development and innovation from a large sample of firms. The relatively new patent databases available have enhanced the opportunity to systematically retrieve data on a large scale.

International patent classification (IPC) data can be used to study whether there has been a growing overlap of technological areas in which different industrial sectors are operating, or whether technological profiles at the industry level remain distinct. IPC codes are a hierarchical way of assigning the category to which every patent belongs. There are 8 sections, 120 classes, 628 sub-classes and about 70,000 groups. This analysis utilized a higher level classification, by which the 628 sub-classes were aggregated into 35 technological fields, and these were further aggregated into five main categories: Electrical engineering, Instruments, Chemistry, Mechanical engineering and Others. (WIPO, 2008)

In order to identify a firm's technological domains, the observed IPC codes in the firm's patent records were identified and classified into technology fields representing the firm's major technological domains. A patent application in each field indicates accumulation of knowledge and advancement in the **technological trajectory** (Fai & Tunzelmann, 2001). The study uses patent data to identify overlapping technology areas and potential trajectory changes with the emergence of convergence and new science-based technologies in the paper industry. The approach is descriptive in nature and relies on the analysis of a large-scale patent database provided by the EPO.

In evaluating the technology dominated emergence of convergence through patents, it has to be remembered that sectors and technologies differ greatly in terms of their knowledge base and learning processes related to innovation. (Pavitt et al., 1989; Malerba, 2005) In addition, distinct industries rely on a variety of mechanisms to protect their intellectual property, as especially process inventions often rely on the non-patent methods of protecting intellectual property rights, such as secrecy or tacit knowledge (Cohen et al., 2000). However, typically the first step to mapping intellectual property landscape of any industry is to create a comprehensive database of patents within the technological sphere of that industry. Such a database would be considered a current overview of the technological developments of the industry, especially those developments that have commercial value or potential profitability. (Pilkington et al., 2009)

Patents represent a very homogenous measure of technological novelty and are available for a long time series. They also provide very detailed data at the firm and technological class level. For the purposes of this study, they therefore represent a very valuable and unique source of data on innovative activity and knowledge spill-overs. Patent data include references to previous patents and non-patent literature opening up the possibility to study spill-overs in technologies and scientific fields between distinct industrial sectors. A meaningful analysis with patent citation data requires that the analyst has to have deep knowledge of the underlying **search reports.**

### 4.2.3 Patent citation analysis

The definition of technological convergence implies that overlaps between technologies (patents) are a precondition for the phenomenon. Therefore, the identification of technological overlaps is an important step in this analysis. The first step is to identify the relevant technical areas which are prone to be influenced by the changing business environment. The second step is then to analyze patents and citations (Figure 17) in the technical areas between the industry actors more deeply based on the findings from the first step.

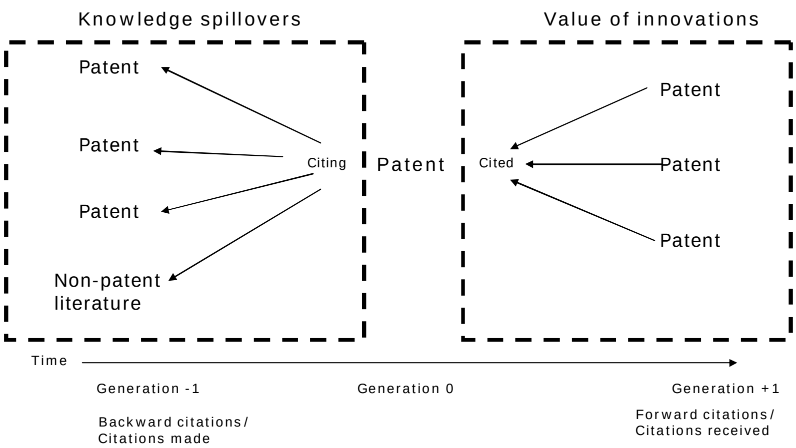


**Figure 17:** Patents and citations

**Knowledge spill-overs between industries**

The earlier papers provided arguments that the foundation for successful paper-based electronics should be possible in the near future, which leads to the big question: will today's paper and chemical companies be the new electronic giants of tomorrow? The backward citation analysis provides insights into the exploration process of new technologies or radical search behavior. Patent citation analysis was conducted in Publication 4 to provide prospects of future competition between the paper and electronics industries. The publication focused on analyzing the knowledge flows and spill-overs (Jaffe et al., 2000; Lukach & Plasmans, 2002) between the industries. The paper introduces the special case of technological change and stages of convergence. Backward citations (i.e. citations made) data of the 84 main RFID industry actors were gathered in order to evaluate the knowledge spill-overs from electronics to the paper and printing firms. Cross-industry citations, as well as self and external citations, were used in order to evaluate the future competitive arena. **Self-citations** would suggest that the firm has a strong competitive position in the particular technology and is in a position to internalize some of the knowledge spill-overs created by its own developments. References to the patents of others are closer to the pure notion of spill-overs. In other words, a more appropriable technology does not transmit readily through external spill-overs. (Hall et al., 2001; Graff, 2003; Hall et al., 2005) Self-citations within the industry describe that of local search (exploitation) generating mainly incremental innovations in existing technological domains. Self-citations beyond the industry span the technological domain indicating capability development in new fields. External citations within the industry can mean intensifying competition within the industry. External citations beyond the industry indicate a radical search or distant search. (See Rosenkopf & Nerkar, 2001)

The technology cycle time (TCT) measure was used to evaluate the **rate of technological innovation** and how quickly firms are **absorbing new technologies**. TCT is defined "as the median age of the patents cited on the front page of a patent document" (Kayal, 1999, 238). The areas **of convergence can be articulated to be characterized by rapid growth** and innovation, and based on that we could anticipate shorter TCT values in converging environments. In addition Bierly & Chakrabarti (1996) found that TCT is significantly faster for firms that predominantly generate new knowledge internally and slower for firms that rely on external sources of new knowledge. Firms' competence development in new fields is dependent on their absorptive capacity. Scientific research, and more specifically basic scientific research, is a major dimension of this capacity to absorb and to internalize new knowledge (Verbeek et al., 2003).

#### 4.2.3.1 Impact of technology-based transformation

The forward citation analysis can provide insights into the value or impact of this potential technology-based industry transformation. The market value of patents is extremely skewed (e.g. Hall et al., 2005), and in the measurement of patent quality (Trajtenberg, 1990; Harhoff et al., 2003; Hall et al., 2005) citations received have been used as a proxy of the impact of technology. For example Pilkington et al. (2009) analysis of inventors in nanotechnology field reveal that only a small fraction of them have patents that also attract many citations. They define key inventors as those inventors whose patenting activity and patenting quality are both greater than twice the average and were able to identify the key contributors to emerging technologies (Pilkington et al., 2009). In our research the aim of the next phase was to evaluate the importance of this technology-based industry transformation. Citations received from the same RFID industry companies were used as a main indicator in Publications 5 and 6. Publication 5 also utilizes the so-called "pioneering innovation approach" and second order citations in order to get more reliable data of the transformation. The patents with no references to previous patents (no prior art), but with many received citations, are called *pioneering innovations*. The pioneering innovations can be considered as real breakthrough innovations in the industry. In addition, the paper discusses the advantages and challenges of using patent-based indicators which are widely discussed in the literature (Griliches, 1990; Cohen et al., 2000; Jaffe et al., 2000; Hall et al., 2001; Michel & Bettels, 2001; Thoma & Torrisi, 2007). Chang et al. (2009) study used patent citation to **find basic patents**, and then classified these basic patents to explore the group characteristics and their technology diffusion. Their study combined two methods to retrieve basic patents: one was to aim at **older patents**; the other one was to use method for **younger patents**. In practice, R&D managers can use their indicator for measuring the strength of patents as the value of the patents. This indicator can provide the trade for patent pricing, licensing, or mortgaging. Furthermore, finding basic patents earlier can help business managers to formulate R&D strategies and improve their decisions for technology planning.

Following the gathering of data from the most significant overlapping technology fields and citations received, the analysis of the future competitive arena was continued in Publication 6. The paper also speculates about the evolution of the value network in converging environments which provide challenges to the firms' Intellectual Property Rights (IPR) management.

#### 4.2.3.2 Anticipating the stages of convergence

In Publication 7, patent citation analysis is used to evaluate both the spill-over effects between the industries and the importance of technology-based transformation. The following of particular industrial sector patents may be detected as citations that allow both backward and forward searching from the patents. References to common technological fields may indicate the convergence of technological competencies between firms in distinct industries. Forward citations (citations made by other patents) are considered to reflect the patent's technological significance, the applicability and the ability of the inventors to benefit from their inventions, namely, their **appropriability**. Patent citations are used, because the value of patent counts as a proxy for R&D success is severely limited by the large variance in the significance of individual patents (e.g. Hall et al., 2005).

Differentiating between self-citations and external citations, and within and beyond industry citations makes it possible to evaluate the search behavior. In converging environments it is expected that the share of self-citations and external citations beyond the industry border are increasing, and eventually convergence beyond the industry border will lead to gradual capability merging and diversification to new fields. The share of self-citations between within and industry citations indicates competence development between established and emerging technologies. The share of external citations received can provide indications of the success of radical industry transformation.

In Publication 8, particular emphasis is given to the validation of the patent analysis method as a tool for technology and innovation policy-making. The patent data are used to identify overlapping technology areas and potential trajectory changes with the emergence of new business sectors. In the framework different kinds of citations are utilized: 1) citations made in non-patent literature (NPL), 2) self-citations within the industry, 3) self-citations beyond the industry, 4) external citations within the industry, 5) external citations beyond the industry, and 6) pioneering innovations. In addition we used 2nd order citations and technology cycle time (TCT), which measures the rate of technological innovation and how quickly new firms are absorbing new technologies.

Patent indicators can also give insight into the process of knowledge transfer from science to technology. The references to the scientific literature have been used in order to evaluate potential convergence in science bases. The average number of references made to the scientific literature within and beyond the scientific discipline have been used as a proxy.

**Table 3:** A summary of the methods and analysis in relation to the publications

| Publication | Methods | Data |
|---|---|---|
| **Publication 1:**<br>*New Perspectives on Industry Transformation through Expansion of the Technology Base and Creative Cooperation* | Qualitative → validation of the case study (opportunities for industry transformation and convergence)<br>Review of the technological discontinuities and industry life cycle theories | **Three round Delphi study:**<br>1st round: 6 interviewees<br>2nd round: 15/23 responses<br>3rd round: 10/15 responses<br>**Alliance activity**<br>The data w ere extracted from *SDC Platinum* |
| **Publication 2:**<br>*Technological Innovation Strategies in Converging Industries* | Quantitative: financial and patent data from companies operating in the emerging business sector | **RFID industry (202 firms); The RFID value chain (38 firms):**<br>Financial and patent data: upstream electronics (13), paper & printing (7), downstream electronics (9), vertically integrated electronics (9) |
| **Publication 3:**<br>*Managing Technological Convergence: Evidence from Printed Intelligence Industry* | Qualitative: semi-structured individual interviews<br>&<br>Quantitative: Descriptive financial and patent data | 12 interviewees – ICT key informants (Firm/Academic); Forest key informants (Firm/Academic)<br><br>Financial and patent data from the RFID industry, 84 firms |
| **Publication 4:**<br>*Analysis of Convergence in Paper and Printing Industry* | Quantitative: Patent citation analyses<br>- Self-citations, within and beyond industry citations<br>- Technology cycle time | Patent data from the RFID industry, 84 firms<br>- Patents and citations made of the players (backwards) |

| | | |
|---|---|---|
| **Publication 5:**<br>*Signals for Emerging Technologies in Paper and Packaging Industry* | Quantitative: Patent citation analyses | Patent data from the RFID industry, 84 firms<br>- citations received (forwards)<br>- pioneering innovations |
| **Publication 6:**<br>*Industry Convergence Analysis with Patent Citations in Changing Value Systems* | Quantitative: Patent citation analyses | Patent data from the RFID industry, 84 firms<br>- Patents distribution Overlapping technologies and citations received |
| **Publication 7:**<br>*Patent Analysis for Analyzing Technological Convergence* | Quantitative: Patent citation analyses | Patent data from the RFID industry, 84 firms<br>- Patents and citations made (backwards) and citations received (forwards)<br>- Self-citations, within and beyond industry citations |
| **Publication 8:**<br>*Patent Citation Analysis as a Tool for Analyzing Industry Convergence* | Patent citation indicators | Patent data from the RFID industry, 84 firms<br>- Illustrative examples of indicators |

Part of the qualitative and quantitative data for this study were collected in the research project "Creation of new business concepts in the intersection of industries: Electricity Networks and Generation, ICT and Forest Industries" conducted by the Technology Business Research Center (TBRC). It examined the changing industry structures of these three tightly interconnected industries. Patent data were collected in the Faculty of Technology Management patent database research.

# 5 A REVIEW OF THE PUBLICATIONS AND RESULTS

This chapter presents the overall objectives and main contributions of each publication. They all deal with related research objectives and questions. The eight different papers combined illustrate the phenomenon under study from different perspectives in order to provide a holistic view of it, thereby answering the research questions posed earlier.

This chapter introduces the research papers that constitute the second part of the dissertation. This thesis consists of eight research articles, the linkages of which are clarified in this introductory part of the thesis. The aim is to discuss the contribution of the separate articles as such, as well as their contribution to the whole convergence analysis and their linkages to each other.

## *5.1 New Perspectives on Industry Transformation through Expansion of the Technology Base and Creative Cooperation*

### 5.1.1 Overall objective

The first publication (Karvonen, Kytölä, Kässi, Mustonen 2008) provides insights into the transformation potential of traditional industries from technology expansion and cooperation perspectives. The paper focuses on the demand trends, technology development of printed functionality, and the incumbents' chances to cope with these emerging new opportunities. The paper thus includes three focus areas: First, it explores the demand trends and the potential effects of information and communication technologies (ICT) on the paper industry (i.e. how quickly the new approach, ICT, might be overtaking the established one). Secondly, the paper examines what kinds of business opportunities are arising at the intersection of the forest and ICT sectors and how the incumbents are coping with emerging growth drivers in the "intersection business." Thirdly, the paper evaluates inter-industry collaboration and the role of complementary innovations in the industry dynamics.

### 5.1.2 Results and main contribution

The Delphi study was used in order to evaluate the future business environment of the printed media and printed functionality. Although the Delphi method can be time consuming and relevance of the results critically dependent on the quality of knowledge captured, overall the results of the Delphi study show that it is possible to achieve a multifaceted and enriched perspective of technology and market evolution rather cost-efficiently with this kind of method.

The findings revealed major threats both to the core assets and core activities in the paper industry. Structural break and the **substitution effect** are expected to continue along the printed and electronic media future value chain convergence. Consumer behavior and advertising are the driving forces in the evolution. The printed functionality market was seen as a promising future area for innovations for many industry sectors along the technological development and convergence of industries. Printed functionality was characterized **mainly as an internally driven competence-enhancing innovation opportunity** for paper companies to find new uses for fiber-based materials. **Complementary** innovations from many fields are required for successful commercialization which provides incentives to collaboration. The findings related to the current state of cooperation in the ICT, paper and printed functionality sectors showed that it was relatively low. Based on the analysis it is not yet valid to evaluate whether the incumbents or new entrants are dominating the emerging industry. The results suggest that inter-firm cooperation with **new entrants** might provide chances to succeed in the emerging business sector.

Printed functionality is an emerging technology area, and prior research by the Delphi method in this area is limited. The anticipatory character of Delphi studies can, through sharing knowledge, augment understanding within the expert group. Although the accuracy of the current study is yet to be confirmed, it revealed many viewpoints of the possible future industry development. Overall, the respondents described the printed functionality market as a small segment with potential for further growth, but a wider commercial breakthrough will take five to ten years. Since commercial applications on a wider scale are still to be seen and there is lack of data about this sector, it is difficult to make precise predictions about future industry evolution and the dynamics between the established and emerging industries. Markets are emerging and incumbents have already invested more in R&D, and new companies are coming to the markets. The results of the alliance activity revealed that overall the paper and ICT industries have not formed many alliances (1990–2006), although some alliance motives related to printed functionality were found, indicating a start in intersectional thinking.

The main contribution of the first publication lies in analyzing an emerging technology area with a qualitative tool to improve foresight. The paper provides insights into industry transformation through technology expansion and creative cooperation, and accordingly makes suggestions for future research on technology development, value chain and value network formation in the emerging industry. This qualitative case study complements the more quantitative inter-industry studies on technological convergence.

## *5.2 Build-up of Understanding of Technological Convergence: Evidence from Printed Intelligence Industry*

### 5.2.1 Overall objective

The main objective of this second study (Karvonen, Lehtovaara, Kässi 2012) was to find out how industry convergence affects the evolution of industries and industry dynamics, as well as to increase understanding of the technological trajectories of industries. In addition, the aim was to provide a framework for analyzing the convergence phenomenon.

### 5.2.2 Results and main contribution

The results of this study revealed the changing value chain structures and industry trajectories in converging environments. An emerging industry is in the early stages of evolution, as the interviews and financial analysis revealed that there was not yet an economic basis for industry convergence. However, the patent data analysis showed indications of trajectory changes as the transformation of the supplier dominated innovation system towards a more science-based innovation system seemed inevitable with the emergence of convergence and new science-based technologies. The results indicate that the core technological trajectories are increasingly becoming more similar between the industries. The development has already started to materialize with the changes in value chain structures. The value chain analysis indicates that there seem to be real new market opportunities for the paper industry. The driving force of the market dynamics is **complementary convergence**, and it is expected that the paper companies play a part in future competition. The restructuring of industries is expected to take place through **inter-firm activities** like partnerships, joint ventures, and mergers and acquisitions. The study provided knowledge about the impacts of convergence on the industry dynamics and strategic management decisions.

The main contribution of this publication is hence to the discussion of different convergence types and providing a preliminary framework for analyzing supply side technological convergence. The results of the study show the importance of the phenomenon and its impacts on industrial evolution and future value chain evolution.

## *5.3 Technological Innovation Strategies in Converging Industries*

### 5.3.1 Overall objective

Prior research has shown the importance of the phenomenon for industry transformation and its potential impacts on industrial evolution. However, the impacts of convergence on the technological basis of industries and its implications for industry and firm-level strategic management have not been addressed adequately. Accordingly, the objective of the third study (Karvonen, Kässi, Kapoor, 2010) was two-fold: the first goal was to evaluate how the convergence affects the technological basis of industries, and the second one was to increase understanding of innovation strategies in convergent environments. The study distinguishes between four generic types of market convergence and discusses how they affect the different industry sectors.

### 5.3.2 Results and main contribution

Prior studies have found that different forms of industry convergence shape the industry dynamics in different ways. Based on prior research and the empirical data, the study found that the market dynamics is driven by complementary technological convergence and internally driven competence enhancing innovation opportunities for the paper industry. The opportunity to create a new kind of technology seemed to have a significant influence on the technological cores and trajectory changes of firms. For the firms operating in converging environments it means continuous scanning of previously distinct industry environments. Strategic decisions between existing and new competences create unique tension between incremental and radical technological innovation strategies. Convergence will increase the interaction and dependency on other industries, and new competences are needed.

Hence, the main contribution of this publication lies in the theoretical and empirical insights that drive our predictions about the effects and stage of the convergence phenomenon and innovation strategies in converging environments. Industry convergence is in the center of understanding industrial dynamics. However, there is still conceptual confusion within the field of convergence and need to provide theoretical and empirical insights into the effects and stage of the convergence phenomenon. Regardless of the growing importance of the convergence phenomenon from the theoretical perspective, there seems to be little consensus over **what convergence means** since its meaning usually depends on the author. Understanding the taxonomies and stages of convergence provide an opportunity to evaluate the effects of this phenomenon.

## *5.4 Analysis of Convergence in Paper and Printing Industry*

### 5.4.1 Overall objective

The importance of the phenomenon as a source of reorganization and transformation of industries indicate that it seems to be strategically important to anticipate fading technological areas and industry boundaries at the earliest possible moment. So, the objectives of this fourth paper (Karvonen, Kässi, 2010) were to study the early stages of convergence by exploring knowledge spill-overs between the sectors and the rate of technological innovation based on technological convergence. Overall the objective of the study is to provide an idea of the stage and competitive effects of convergence. In addition, the paper also tries to contribute to the conceptual confusion by providing clarity to the definitions and different types of convergence.

### 5.4.2 Results and main contribution

Overall, the findings show indications for knowledge spill-overs and convergence between the industries. The empirical evidence collected provides prospects to the future competition between the actors. In this special case of technological change it is extremely important to identify the actors that the emerging new business sector is influencing and its impacts on them. Differentiating between different types of citations (see Figure 18) provides views to the future competitive arena. Self-citations are used as a proxy of capability accumulation, within industry external citations as a proxy for competition and beyond industry external citations as a measure for diversification.

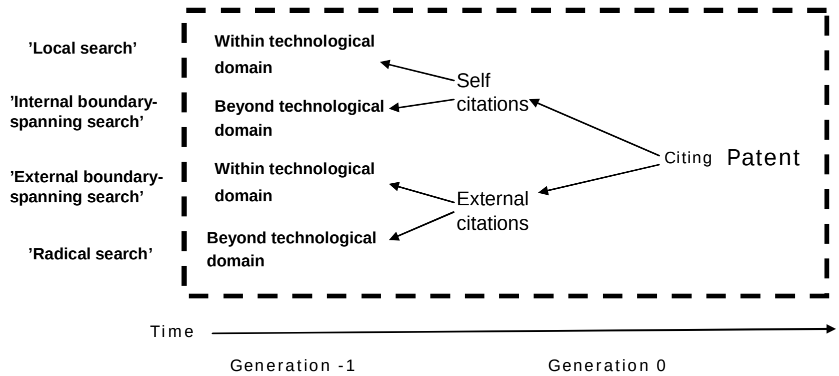


**Figure 18:** Types of patent citations for evaluating knowledge spill-overs

Using patent citation data in industry analysis makes it possible to recognize convergence trends early and to get an idea of the stage of the convergence process. Hence, the main contribution of this publication lies in evaluating the knowledge spill-overs and absorptive capacity of the actors. Differentiating between self-citations and external citations, and within and beyond industry citations makes it possible to evaluate the search behavior. In converging environments it is expected that the share of self-citations and external citations beyond the industry border are increasing, and eventually convergence beyond the industry border will lead to gradual capability merging and diversification to new fields. Patent citations offer fascinating insights into the paths of search and explorations industries and firms follow, and provide a possibility to get an idea of the stage of convergence in the emerging business sectors. Overall, patent analysis can be regarded as one of the most effective methods to keep in touch with trajectory changes for considering industry evolution. It is, however, impossible to predict reliably the impact and competitive consequences only based on data about citations made.

## 5.5 Signals for Emerging Technologies in Paper and Packaging Industry

### 5.5.1 Overall objective

Earlier empirical findings from growing intra-industry diversity in patenting and the knowledge spill-over effect support the view of the convergence hypothesis and trajectory changes. The main objective of this fifth publication (Karvonen, Kässi, 2010) is to evaluate the impact of this technology-based industry transition. Accordingly, different kinds of citations received were used to evaluate the impact and value of technology-based industry transition (Figure 19).

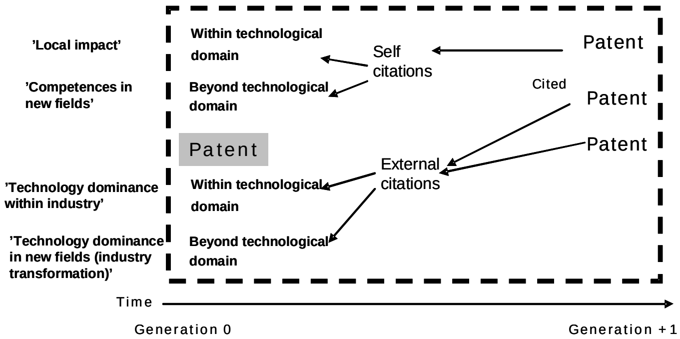


**Figure 19:** Forward citations as a proxy of technology competences

Another objective was to evaluate industry ability to create breakthrough and long-lasting innovations. The patents that have not made any references to previous patents (no prior art), but have been cited a lot (forwards) are called *pioneering innovations* (Figure 20). The pioneering innovations that have been frequently cited both in the first and second generation can be thought to be real breakthrough innovations in the industry.

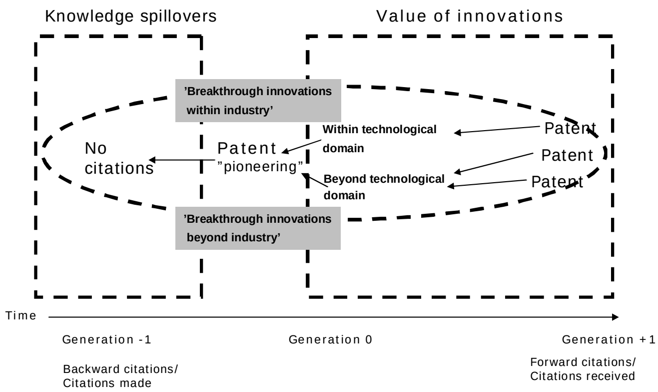


**Figure 20:** The pioneering innovations

Additionally, the paper discusses the opportunities and challenges of using patent data in the industry analysis.

### 5.5.2 Results and main contribution

The findings of the study indicate that there seems to be a real convergence process between the industries, as external citations beyond the technological domain provide some indications of technological success in the paper industry. Different citation types can provide valuable insights into technology accumulation and dominant technology actors. For example, self-citations typically indicate a strong competitive position in the particular technology, and the firms are in a position to internalize the knowledge created by their own development. The results of paper & printing firms' self-citations mainly mean citations received in their traditional fields of core competences.

The empirical results show that the distribution of pioneering innovations is quite similar compared to patents distribution, and the actors have mostly made these more radical innovations in their own strong technological fields. However, the paper and printing firms' pioneering innovations have increased especially in optics, semiconductors, computer technology, and the basic communication processes, but compared to the other electronics industry actors, the firms still have made substantially less pioneering innovations. In the sample there were 306 inventions that had received at least 100 citations, and from these over 60% were made by integrated electronics companies, of which IBM was the dominating innovator. However, it is methodologically challenging to evaluate an emerging business with this kind of method, because time is needed to accumulate significant information about the citations. The main contribution of this study lies in creating preliminary indicators for evaluating the impact of technology-based industry transformation.

## *5.6 Industry Convergence Analysis with Patent Citations in Changing Value Systems*

### 5.6.1 Overall objective

The first study revealed the current value chain convergence development (Figure 7) and, together with the second study, provided some prospects of potential value chain reconfiguration in the emerging new industry.

The main objective of this sixth study (Karvonen, Kässi, 2011) was to evaluate how patent citations can be used to evaluate future value chain competition in converging technology fields. The goal of the study was to identify overlapping technology areas and provide insights into the future competitive arena. Ambitiously, the paper also sought to validate the patent citation method as a tool for technology and innovation policy purposes.

### 5.6.2 Results and main contribution

The definition of convergence means that distinct industries are merging in a new field providing opportunities for new inventions for distinct industry sectors. This definition implies that overlaps between technologies are a precondition for the phenomenon. The empirical findings of the study revealed that the paper companies are increasingly patenting in the emerging fields of computer technology, audio-visual technology, semiconductors, and optics. Relative technology trends between the actors and the citations received shed light on future technology competition. In complementary technological convergence, different technologies are brought together to create new technology and the degree of fragmentation of patents connected to a given technology typically increases. The finding suggests that traditional vertical value chain structures change to horizontal value networks. This means that technological development should never be evaluated as an isolated entity but in the context of the environment and the whole value network structure evolution. The system perspective is needed in order to understand the changing value system and the interaction within value network relations.

Patent analysis focuses on technology development and it is clear that it alone is not enough to understand the system perspective or systems thinking. However, for example the growing importance of outsourcing business activities is one of the drivers for value network formation, and patent information has been widely utilized in the identification and assessment of potential sources of external technology creation, like mergers & acquisitions or alliances, human resource management (e.g. Ernst, 2003), and social network analysis (Yoon & Park, 2004; Huang et al., 2010). However, to gain a deeper understanding, patent analysis is not sufficient to reveal the interaction within value network relations.

From the patent citation analysis viewpoint, there are severe methodological challenges related to the different patent systems, and in interpreting the results, a deep understanding of the patent systems is required. In addition, linking industrial sectors and technologies with technology market and product market competition is difficult. The relevant IPC codes primarily refer to technologies and only sometimes products are directly addressed. The production and function of products are based on technologies, and most products use a variety of technologies. Sectors on the other hand are defined by typical products, but many firms produce a broad variety of different products, so that in reality sectors describe the firms' main economic activities. It is necessary to address whether the patterns we observe stem from unrelated technological categorization or industrial sector classification. In the analysis, for example, the paper made no attempt to connect patenting and product market competition.

The main contribution of this study lies in identifying systematically overlapping technology fields and providing insights into the future competitive arena. However, a lot has to be done before the patent citation method is ready for technology and research policy purposes.

## *5.7 Patent Analysis for Analyzing Technological Convergence*

### 5.7.1 Overall objective

The earlier papers showed that following industrial sector patents revealed citations that allow both backward and forward searching from the patents. The seventh paper (Karvonen, Kässi, 2011) evaluates industry transformation with patent data citation. The study evaluates and recognizes overlapping technology fields and examines the spill-over paradigm and the stages of convergence. The main objective is to evaluate how patent citation analyses can be used to analyze technological convergence.

### 5.7.2 Results and main contribution

This publication analyzes knowledge spill-overs and the market value of inventions in order to provide insights into the future competitive arena in converging environments. Overall, the recognized trends of the growing overlaps show indications for convergence between the industry sectors. Therefore, from the traditional electronics industry companies' knowledge perspective, the study points out their future competitive area. Backward citations can help to recognize the spill-over paradigm and early signs of technological convergence, as well as competitors coming from beyond industry boundaries. Forward citations are used as a proxy of the impact of technological innovations and success of technology-based industry transformation. The main contribution of the presented patent citation methodology is to provide new insights into the analysis of industry evolution, technological innovations and business development related to converging industries and technologies. Differentiating between citation types provides more comprehensive prospects of the future technology competitive environment. The patent-based indicators can provide insights into the transformation dynamics of basic mature industries.

## *5.8 Patent Citation Analysis as a Tool for Analyzing Industry Convergence*

### 5.8.1 Overall objective

Prior studies have shown the importance of understanding the nature and stage of change in converging environments. Different patent analysis methods have been used to evaluate technology-based convergence. Accordingly, the objective of this eight study (Karvonen & Kässi, 2011) was two-fold: the first objective was to provide insights into the use of patent data in analyzing emerging business sectors, and the second one was to provide a conceptual lens for analyzing and anticipating the early stages of convergence. The references to non-patent literature have been used to trace the linkages between scientific research and technological innovation in the converging technological environment. Overall, the complex interaction between science, technology, market, and industry convergence creates a great need to develop a tool for strategic R&D management. This study synthesizes the convergence evolution and empirical indicators (Figure 21) used in the convergence analysis.

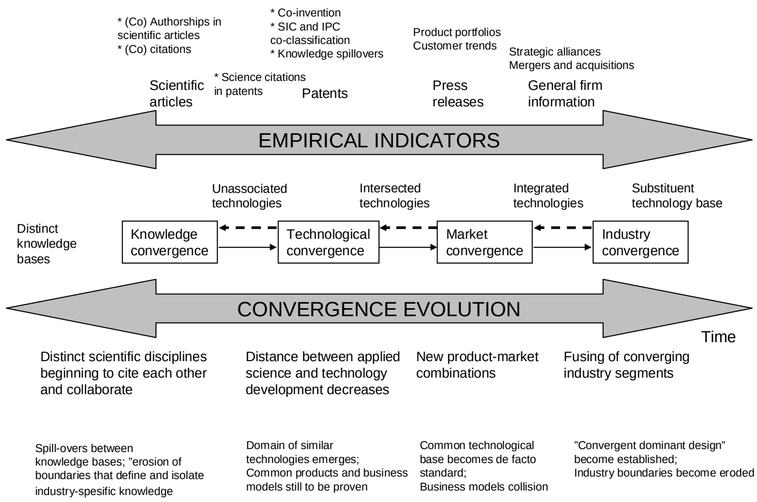


**Figure 21:** The convergence evolution (Adapted from Hacklin, 2008; Curran & Leker, 2008)

### 5.8.2 Results and main contribution

The citations in the patents open up the possibility of tracing trajectories and the search behavior of industries. Patent citation indicators (Table 4) are used with two distinct industries, the paper and electronics companies, as a test environment to evaluate the importance of this technology-based industry transformation.

**Table 4:** Patent citation indicators for convergence analysis

| **Category** | **Sub-category** | |
|---|---|---|
| Non-patent literature citations (exploration) | Within scientific discipline | |
| | Beyond scientific discipline | |
| Backward citations (exploration) | **Self citations** | within technological domain |
| | | beyond technological domain |
| | **External citation** | within technological domain |
| | | beyond technological domain |
| Forward citations (exploitation) | Self citations | within technological domain |
| | | beyond technological domain |
| | **External citation** | within technological domain |
| | | beyond technological domain |
| Pioneering innovations | Within technological domain | Beyond technological domain |
| Technology cycle time | Rate of technological innovation | |
| | Firms absorptive capacity | |
| 2nd order citations ('breakthrough innovations') | Within technological domain | Beyond technological domain |

Overall results from the study are that the citation analysis method sheds light on the technology competitive arena. Patent citation indicators, such as backward citations, forward citations, pioneering innovations, and technology cycle time were used to evaluate the search behavior and importance of this technology-based industry change. The long accumulation process of forward citations restricts their use in the evaluation of current or very recent innovations. Otherwise the results of these empirical indicators do not seem to be in conflict with real observations in the industry.

The empirical findings, however, revealed some major conceptual and methodological challenges in studying the complex phenomenon of convergence in industry evolution. Patent indicators can give insights into the process of knowledge transfer from science to technology. The average number of references made to the scientific literature within and beyond a scientific discipline in a patent produced in a particular sector was used as a proxy of science convergence in the sector. The technological convergence in the test environment, however, has not meant convergence in sciences (see Karvonen & Kässi, 2011). The technology markets are related to science (science/technology interaction) and the product markets (technology/product market interaction). When evaluating the competitive and complementary effects analytically, one challenging methodological problem is with the interaction of patents and product markets. The patent literature does not contain a reliable method to map patents in product markets. It seems evident that in reality the stages of convergence co-evolve and interact in rather complex ways compared to the linear model in which the progress of science was essentially exogenous and technological advances were merely the outcomes of applied research and development efforts.

The paper presents the conceptual analysis of methods in patent citation researches which have been applied to the one and same data material. It has been possible to verify the patent citation analysis methods in relation to the empirical test environment (Table 5).

**Table 5:** Summary of methods and main empirical findings

| Method | Expected findings | Observation | Validity | Reliability |
|---|---|---|---|---|
| Non-patent literature (NPL) citations made | References to the scientific literature beyond the industry discipline increasing | Ambiguous results | Unclear | Medium (repeatable) |
| Backward citations (citations made) | Share of self-citations beyond technological domain increasing | Shows convergence (or fusion) | Yes (subject to limited case study results) | Strong. Corresponds to expected results, repeatable. |
| | Share of external citations beyond technological domain increasing | Shows convergence (or fusion) | Yes (subject to limited case study results) | Strong. Corresponds to expected results, repeatable. |
| Forward citations (citations received) | Share of self-citations beyond technological domain increasing | Does not show clear results | Unclear (due to limited observations) | Medium. Accumulation of data over time. |
| | Share of external citations received beyond technological domain increasing | Does not show clear results | Unclear | Medium. Accumulation of data in course of time. |
| Technology cycle time (TCT) | Rate of technological innovation high in the areas of convergence | Shows convergence (or fusion) | Yes | Strong/medium |
| | TCT is faster for firms generating new knowledge internally | Clear results in electronics; unclear in paper and printing due to the limited findings | Valid. Strong in electronics; weak in paper & printing | Strong |
| 2nd order citations | Breakthrough innovations beyond technological domain increasing | Clear results in electronics; unclear in paper and printing due to the limited findings | Weak. Interpretation not clear | Medium (repeatable) |

The presented patent citation methodology provides new insights into the analysis of industry evolution and technological innovations related to converging industries and technologies. Further research is needed to understand more deeply the relations and interaction between the different stages in the convergence or fusion process. The main contribution of the study lies in providing a conceptual lens for analyzing the convergence and methodological development of patent analysis indicators for converging environments.

## 5.9 Summary of the results of the whole study

The research questions and the results reported in each publication are summarized in Table 6 below.

**Table 6:** A summary of the research questions and the main results of the whole study

| | **Publication 1** | **Publication 2** | **Publication 3** |
|---|---|---|---|
| **I Clarifying convergence and its impacts** | | | |
| **Title** | New Perspectives on Industry Transformation through Expansion of the Technology Base and Creative Cooperation | Build-up of understanding of technological convergence: Evidence from the printed intelligence industry | Technological innovation strategies in converging industries |
| **Main research question** | What kinds of business opportunities are arising at the interface of the paper and electronics sectors? | How can the convergence phenomenon and impacts of convergence be clarified? | How does convergence affect the technology base and innovation strategies of industries? |
| **Main results** | The radical trajectory of industry evolution is in the convergence phase and forces a renewal in the paper industry. Printed functionality offers one potential diversification opportunity through technology expansion and cooperation with new entrants (complementary innovations).<br>Strategic alliances and inter-disciplinary partnerships can help to face industry complexity. | The identification of the nature of change is crucial as the forms of industry convergence shape industry dynamics in different ways.<br>The findings show indication of increasingly similar technological trajectories and changing value chain structures towards the end of the value chain (integration). | The convergence seems to have a significant influence on the technological cores creating unique tension, new capability development and validating existing competencies. The phenomenon presents internally driven innovation opportunity for the paper industry (established). |
| **Conclusions and limitations** | - The phenomenon is an increasingly important factor in industrial evolution<br>- What does convergence mean? | | |
| **II How can patent analysis be utilized in analyzing technological convergence?** | | | |
| **Title** | **Publication 4**<br>Analysis of Convergence in Paper and Printing Industry | **Publication 5**<br>Signals for Emerging Technologies in Paper and Packaging Industry | **Publication 6**<br>Industry Convergence Analysis with Patent Citations in Changing Value Systems |
| **Main research question** | What is the mechanism of knowledge spill-overs based on technology convergence? | How can the impact of technology-based industry transformation be evaluated? | How can patent citations be used to evaluate future value chain competition and the impact of technology-based industry transformation? |
| **Main results** | Different backward citation types offered paths for searching and exploring industry trajectories, and provided an idea of the stage of asymmetric technological convergence. | Forward citations can provide valuable insights into the technology accumulation and dominant technology actors, although evaluation is not sensible | Systematicalexamination of overlapping technology fields and citations received can provide useful insights into the future value chain competition. The stages of |

| | | | |
|---|---|---|---|
| | | for very recent innovations. | convergence and interpreting the results require further studies. |
| **III How can the early stages of convergence be anticipated?** | | | |
| **Title** | **Publication 7** Patent Analysis for Analyzing Technological Convergence | **Publication 8** Patent Citation Analysis as a Tool for Analyzing Industry Convergence | |
| **Main research question** | How can the stage and effects of technological convergence be evaluated? | How can patent citation indicators be used to analyze the early stages of convergence? | |
| **Main results** | Backward citations can be used to recognize the early signs of change in search trajectories which can help to recognize the new competitors coming from beyond industry boundaries. The slow progress of accumulation of forward citations makes them quite a useless *ex ante* impact indicator. | The patent citation analysis indicators shed light on the technology competitive arena and the search behavior of industries. Technological convergence has not meant convergence in science bases. The findings revealed some major challenges in studying the interaction of different phases in the convergence process. | |

# 6 DISCUSSION AND CONCLUSIONS

## *6.1 Answering the research questions*

The overall objective of this study was to answer the question of how to anticipate technological convergence and its impacts on industrial evolution. In order to achieve this, three research questions and eight sub-questions were posed. The first main research question was: ***How can the convergence phenomenon and its impact on industrial evolution be clarified?*** Answering this question required understanding about the definitions and different types of convergence. The conclusions of the study emphasize the need to understand the nature of change and stage of convergence, as the different forms of industry convergence shape the industry dynamics in different ways. The study tries to reduce confusion behind the concept of convergence by providing analytical clarity, which improves the theoretical coverage of the concept. **The study uses the term *convergence* for the blurring of boundaries between two or more hitherto disjoint industries, thus called *industry convergence*.** Convergence leads to the formation of a new industry segment either replacing the former segments or complementing them at their intersection. In practice, however, it is very difficult to separate the exact nature and consequences of convergence, as the phenomenon often evolves concurrently both as convergence in substitutes and convergence in complements.

Regardless of these challenges it is important to make a distinction between these kinds of archetypes, because their implications e.g. to competition and cooperation are very different. Empirically the study provided insights into the dynamics of industry change and technological trajectories of basic mature industries. The emerging new industry segment between the paper and electronics industries offers internally-driven innovation opportunities for the paper industry. Overall, this qualitative case study revealed the importance of the phenomenon in understanding the industrial dynamics and the need to anticipate the early stages of convergence. The main contribution in response to this research question is, thus, in elaborating on the nature and implications of convergence, and consequently in suggesting future research areas.

The second main research question was: ***How can patent analysis be utilized in analyzing technological convergence?*** Several conclusions were drawn. Firstly, different kinds of patent citations can offer fascinating insights into the industry paths of search and exploration of new technological opportunities. The patent analysis provides an idea of the industry trajectories and competitive effects of convergence. Secondly, the findings revealed that patent citations can be utilized in trying to evaluate the future value chain competition and impact of technology on technology-based industry transformation in converging industry environments. Thirdly, the study also revealed methodological challenges in evaluating the emerging business sectors with patent citation data. Regardless of the challenges, the patent analysis is quite well suited to analyzing technological convergence and its potential effects on industry evolution.

The third research question was: ***How can the early stages of convergence be anticipated?*** In response to this, the study provides a conceptual lens for analyzing the stages of convergence. Empirically the presented patent citation methods give new insights regarding the analysis of the early stages of convergence. The patent data are used to identify overlapping technology areas and potential trajectory changes with the emergence of new business sectors. Patent citation indicators, such as references made to patents and non-patent literature and citations received, pioneering innovations, and technology cycle time are used to evaluate the importance of this technology-based industry transformation. The empirical data yielded different results, but the results and conclusions of the empirical part do not seem to conflict with real observations in the industry. It has been possible to verify the patent citation analysis methods in relation to the empirical test environment.

## *6.2. Theoretical contribution and managerial implications*

This study contributes to the developing research on industry evolution in convergent environments in two major areas. **The first contribution lies in the fact that this study is one of the first researches to link several important concepts in analyzing industry evolution, technological discontinuities, path-dependency and technological trajectories, technological interfaces as a source of industry transformation, and the evolutionary stages of convergence.** The limited understanding of the phenomenon of convergence has so far failed to come up with a strong theoretical foundation for many aspects related to the convergence process. This is seen in the literature as a lack of consistent definitions and implications of the phenomenon. Convergence has so far been studied mostly in the ICT sector since empirical work in other convergent settings is missing. Our case study is historically based on two very distinct industries of the paper and electronics companies as a test environment to evaluate the importance of technological convergence as a source of industry transformation. Overall the study develops methods for analyzing industry change in converging environments better than traditional industry analysis methods. The use of these methods provides new insights into anticipating changes in industry structures and supporting firm strategic management.

**The second major contribution is in the methodological use of patent indicators** in analyzing technological convergence. This dissertation utilizes novel patent-based indicators in the analysis of technological convergence elaborating on technology competition, capability and competence development, knowledge accumulation, knowledge spill-overs, and technology-based industry transformation. The advancements of patent analysis methods have provided methodological insights into the use of patent data in technology forecasting and research. Combining the industry evolution perspective and the convergence view of industrial evolution has contributed to developing the industry analysis theory and improving the methods to study the development of converging industries. It also offers a foundation for further development and generalization of knowledge about the research area.

### 6.2.1 Clarifying the theoretical level

**Implications for industry and convergence research**

Based on reviewing the literature of industry life-cycle theories, technological discontinuities, evolutionary economics, and technology trajectories, a generic understanding of industry transformation and industrial dynamics was generated. Theoretical perspectives provided explanations for understanding the rules of industry change in the environment, the potential effects of technological discontinuities, the role of complementary assets in industry evolution, and how competitive and cooperative relationships might evolve in the formation of a novel business. The understanding of technology and its evolution is mainly based on the ideas of evolutionary economics, with the path-dependent nature of knowledge and technology trajectories. Patents and patent citations can be used to evaluate trajectory changes.

Regardless of the growing importance of the convergence phenomenon from a theoretical perspective, there seems to be little consensus over what convergence means. The taxonomies of convergence (e.g. Stieglitz, 2003; Christensen, 2011) can help in understanding the nature of the convergence process. Basically, convergence across technologies, product markets or industries may be substitution-based or integration-based (complementary convergence). In substitution-based convergence, the emerging new business sector will replace the former segments, and, in integration-based convergence, it will complement them at their intersection. (Dowling et al., 1998; Christensen, 2011). The technology substitution type of convergence usually means **creative destruction**, increased competition, new actors' entry to the markets, incentives to seek defensive vertical and horizontal mergers, the increased importance of complementary assets, and horizontal integration (Hacklin, 2008; Lei, 2000; Bauer, 2003; Tushman & Anderson, 1986; Rothaermel, 2001; Tripsas, 1997). The complementary type of technological convergence may decrease the intensity of competition, value chain reconfiguration, incentives for collaboration in alliances, joint ventures, or mergers. This is typically more competence-enhancing type of discontinuity for established industry actors. (Tushman & Anderson, 1986; Wirtz, 2001; Bauer, 2003) So, the basic question in the above-mentioned categories is how the new industry segment affects the established industries**:** 1) creating totally new business sectors (not affecting the established industries); or 2) creating an area of fusion between the industries (at least partly substituting the established industries, i.e. cover needs already provided by existing services). In converging markets it is very important to identify the potential complementary or competitive convergence possibilities as early as possible. In complementary convergence, the cooperative paradigm is dominating, and, in competitive convergence, the substitutive paradigm is dominating. In practice, however, there is often competition and cooperation at the same time, or the so-called coopetitive paradigm between the industries. Complementary convergence creates the most opportunities for successful cooperation between the established industries or with new entrants.

The evolutionary phases of the convergence process (Hacklin et al., 2009) have led to a discussion on the stage model of inter-industry innovations. Even though the relationships between the stages of science, technology, product markets, and industry are very complicated, the evolutionary stages provide a starting point to understanding how the convergence process might evolve. In the convergence studies, the theoretical basis of this study is hence in the discussion of different convergence types (e.g. Rosenberg, 1963; Stieglitz, 2003; Curran & Leker, 2010; Christensen, 2011) and their impacts on industry evolution (e.g. Tushman & Anderson, 1986; Tripsas, 1997; Rothaermel, 1999; Sadowski et al., 2003; Rothaermel & Hill, 2005), and in anticipating and monitoring the stages of convergence (Hacklin, 2008; Curran & Leker, 2010). In the light of many failed convergence predictions on the one hand and their high strategic importance (Curran et al., 2010) we see that industry convergence should be at the heart of understanding industrial dynamics and the research agenda of technology management and firm strategy. Overall, the linkages between industry evolution, technological discontinuities, convergence, technology trajectories, and innovation management provided theoretical considerations and perspectives to the convergence phenomenon and industrial dynamics in converging industry environments. Methodologically, the focus of this study was in technological convergence where patent data were used to evaluate the technological trajectories and potential trajectory changes in converging environments. Recognizing trends early is important for policy makers as well as technology managers. Patent analysis can be regarded as one of the most effective methods to keep in touch with trajectory changes when considering industry evolution.

## Methodological contribution

The complex interaction between science and technology provide a great need to forecast emerging technologies and tools for strategic R&D management. In case of emerging technologies use of science and patent indicators has been used on the technology assessment and forecasting studies (e.g. Daim et al., 2008; Daim et al., 2007; Kim et al., 2010; Daim & Jordan, 2008). Regarding to these studies the major add and contribution in this study is the use and development of patent citation indicators which have not been used in other studies of technology convergence (see e.g. Gambardella & Torrisi, 1998; Bores et al., 2003; Fai & Tunzelmann, 2001; Curran & Leker, 2010). The developed patent citation methodology is based on literature of patent citation indicators (e.g. Jaffe et al., 2000; Rosenkofp & Nerkar, 2001; Harhoff et al, 2003, Hall et al, 2005; Rafols & Meyer; 2010).

Patent data have been used in some studies in analyzing technological trajectories (e.g. Patel and Pavitt, 1997; Andersen, 1998; Suzuki and Kodama, 2004; Storto, 2006; Verspagen, 2007) and technological trajectories in converging industry environments (e.g. Gambardella & Torrisi, 1998; Fai & Tunzelmann, 2001). Patent citations can offer fascinating insights into the paths of search and explorations industries and firms follow, and provide a possibility to get an idea of the stage (mainly backwards) in the emerging business sectors and impact (mainly forwards) of the convergence phenomenon. Patent citation analyses also give indications for strategic conclusions, e.g. for competition, accumulation of knowledge, changes in the competitive situation, potential next moves of competitors in the market, and the future competitive arena. Differentiating between citation types provides more comprehensive prospects of the future technology competitive environment. In converging environments it is expected that the share of self-citations and external citations beyond industry borders are increasing, and eventually convergence beyond the industry border will lead to gradual capability merging and diversification to new fields. Forward citations can be used to evaluate the importance or impact of this technology-based transformation. However, it is difficult to evaluate the significance of industry transformation, because time is needed to accumulate significant information about the citations.

Overall, the patent-based indicators can provide insights into the transformation dynamics of basic mature industries, which was the focus of this study. Patent indicators can also give insight into knowledge transfer between science, technology, and the industry. The citations to the scientific literature have been used in order to evaluate potential convergence in science bases and the average number of references made to the scientific literature within and beyond scientific disciplines has been used as a proxy (Karvonen & Kässi, 2011). The advantage of utilizing publicly available patent-based indicators is the fact that it reduces personal bias and estimation that requires expert opinions. However, patent analysis alone cannot provide answers to potential complementary and substitutive effects on the product markets. Such studies that take into account the competitive interaction of firms both in the technology and products markets would provide us with important insights into concrete complementary and substitutive effects on product market and industry competition. The methodological contribution of this study relates to novel patent citation indicators which have not been used before to systematically analyze technological convergence. The presented patent citation methodology provides new insights into the analysis of technological innovations related to converging industries and technologies.

### 6.2.2 Managerial implications

There are a lot of data and indicators related to the business environment. However, the interpretation of this data and making sound decisions is not an easy task for strategy planners. This requires understanding the trajectory of industry change (McGahan, 2004) and maintaining the organization’s ability to navigate through the cycles of technological change, characterized by technological discontinuities, creative destruction, or creative cooperation. The convergence as a special form of technological change typically means changes in industrial structures and the strategic direction of companies. Managerial efforts for directing the firm’s marketing and financial operations provide a solely incremental instrument for survival and improving profitability. On the contrary, the capability to ride waves of product and process innovations affect not only profitability, but also, in the long term, the viability of the entire firm (Anderson & Tushman, 1991).

One of the key strategic impacts of convergence is that it is driving companies with traditionally distinct and stable business models into the same territory. Managerially it is very important to identify the actors that the emerging new business sector is influencing and the potential substitution and complementary effects on the different industry sectors (Figure 22). For managers one challenge in this kind of analysis is how to reliably recognize the effects of convergence, *ex ante*, because in practice both forms of convergence are occurring in parallel. For example, **value chain convergence** in the printed and electronic media has for long also complemented the growth of the printed media, and only very recently the structural break and substitution effect due to the Internet and e-books are eroding profits by taking away business from the market. **The technological convergence** between paper and electronics is mainly technology integration providing both substitute and complementary effects in the product markets. Smart paper and package products and hybrid media applications are examples of product **complements** in the intersection of the paper and electronics industries. In this kind of technological convergence on the supply side, the different technologies of industry sectors are brought together to create new technology. The new industry segments are often quite challenging, as firms have to utilize knowledge and technologies not within their traditional core fields of expertise. In most cases of convergence, sourcing the essential knowledge from beyond their own industry is necessary and key to successful innovation management. The low investments in research and development activities may, however, decrease the paper firms' ability to gain innovation from outside the company and low profitability (cash reserves) makes acquisitions impossible.

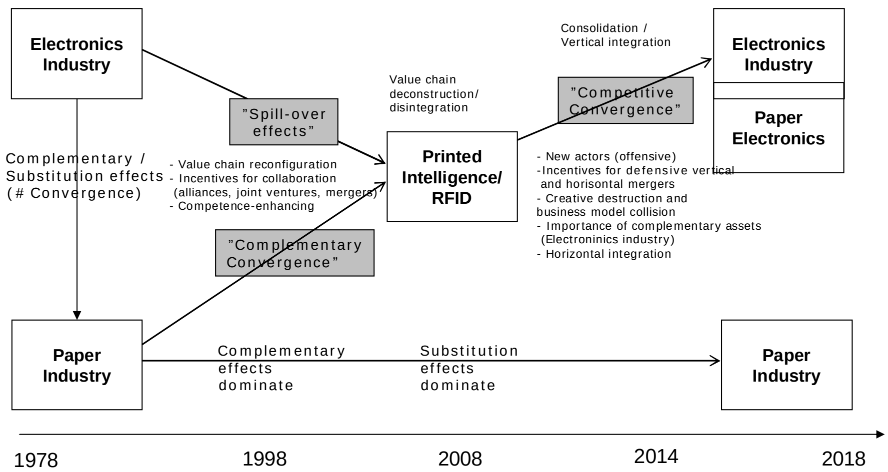


**Figure 22:** The illustration of the evolution of the paper/printing and electronics industries

The printed functionality (e.g. printed barcodes, interactive displays, freshness sensors, humidity sensors, printed RFID, printed battery etc.) makes it possible to create new products for new markets building partly on existing technological capabilities. Complementary technological convergence is at the moment the driving force in the development providing a plethora of new possibilities at the outposts of the paper industry leading to opportunities and challenges alike. It seems that the new rules of the competitive environment result in alliances and mergers and acquisitions reaching beyond previously established industry boundaries. In this potential industrial convergence phase, competing and collaborating at the same time will be a key element throughout the convergence process, which poses challenges to partnering and the alliance capabilities of firms. Complementary innovation should strive to gain competitive advantage by searching for those strategic partners that enhance the critical downstream or upstream value chain activities.

Triggered by process innovations in the printing and electronics industries, the phenomenon of convergence has started to materialize by promoting the creation of higher value-added substitute or complementary products. This new technology is potentially replacing some conventional electronics (e.g. printed RFID and ultra-low cost tags are potentially replacing and substituting the silicon-based technology). Therefore, from the point of view of the electronics industry, the new technology presents partly competence-destroying discontinuity requiring new technical skills and makes some electronics industries' traditional competences obsolete. In the **technology substitution** type of convergence, industry sectors with different technological capabilities, i.e. technological bases, become similar in the sense that they can satisfy the same set of needs. At the moment the electronics industry does not seem to have many incentives to cooperate with the paper industry, and, so, the paper industry transformation could happen through technology expansion and creative cooperation with **new entrants**. Regardless of the strategic problems of economies of scale-based firms, because of complementary innovations there clearly seems to be a need for a business model to generate niche products with entrants. As the evolution continues it is expected that the effect of competitive convergence will increase leading to an increasing substitution effect of paper-based electronics. Thus, in the future, paper and printing firms play a part in the competition (coopetition) with electronics firms, but it is far too early to speculate whether the paper industry actors will come tomorrow's electronic giants. In that case there will be real business model collision in the next 3–5 years or mergers and acquisitions of giant electronics industry actors. For the industries the combination of convergence and path dependence also produces unique tension, as firms are expected to remain consistent with their industry, while on the other hand convergence induces them to diversify by venturing into new markets. The industry seems to be in a phase where the existing technologies develop incrementally and technological interfaces are seen as potential radical products and process innovations. In the tension between focus and diversification strategies, a balance between the old and the new is also needed to manage both kinds of innovations.

It is important to understand the nature of the convergence process, and monitoring the stages of convergence can help to do right and timely strategic management decisions. Anticipating convergence would enable firms to form strategic alliances or acquire new technologies at early stages in the process of convergence. Thus, it seems to be strategically important to anticipate fading technological areas and industry boundaries at the earliest possible moment (Curran & Leker, 2010). Companies operating in convergent environments require more understanding about the evolutionary phases of convergence in order to react to the challenges of their innovation activities. Patent analysis can help in recognizing the trends early on. It can show the overlapping technology fields, knowledge spill-overs (citations made) and indicate the value of innovations (citations received). Distinguishing between different kinds of citations can give indications about the future competitive arena: within and cross-industry self-citations indicating capability development, external citations within the industry indicating competition, and external citations beyond the industry indicating diversification to new fields. Citations received can be used as a proxy of the value of inventions (approbriability) and different citation types can give indications of the impact and the market power of actors in emerging technology fields. Presented in this thesis, the attempt to identify patent classes either as substitutes or complements is an important first step in the assessment of overlapping technology areas. Patent analysis can be used for monitoring the intersections of new fields and convergence. However, simply **patent analysis does not reveal whether the inventions are substitutive or complementary,** and it is impossible to evaluate exact competitive consequences only based on patent data. Overall, the main managerial implication was in trying to support the foresight of industrial changes and strategic directions of companies, and giving tools for organizations' commercial renewal.

Overall it seems evident that the importance of intellectual property management (IPR) will increase in the forest industry. Previously massive investments were necessary for success, but the new innovations are changing the business logic in the industry. In the current and future business environment, partners from several technology and industry fields are used in order to combine complementary capabilities and create new business. There are many ways to protect intellectual property, such as trademarks, registered designs, utility models, and patents. In the future with IPR or complementary assets some part of the value added may remain in the high cost country, like Finland, in the case that manufacturing is split between many countries and only technology development or some other crucial functions stay in the original innovator and technology developing country.

## *6.3 Limitations*

There are several limitations in this study. **Firstly**, the case is mostly related to **science and technology**-based innovations which represent only a small proportion of all innovations. **Secondly**, the qualitative futures study analysis had to be limited to Finland because of the time consuming nature and difficulty of data collection. The members of the expert panel in the Delphi process were chosen on an informal basis. Regardless of the careful choosing of the panelists, there is always a possibility of bias in the respondents' selections and answers. **Thirdly**, this study has provided evidence on firms' patenting behavior in the selected market area (RFID) between distinct industries (the paper and electronics) and focused the analysis on the most interesting technology areas from the paper and printing industry point of view. Thus, this study mostly evaluates technology development in converging environments. It has to be remembered that technological and business (product market) diversification are not the same issue (Gambardella & Torrisi, 2002; Bröring et al., 2006; Palmberg & Martikainen, 2006). One major assumption in the study was that patent and citation trends and indicators would translate to commercial success. Although many research studies cited in the methodology section agree with this assumption, there are many dynamic factors that may invalidate the assumption. What can be concluded accurately is the amount of research and development being done. (see Harell & Daim, 2009)

**Fourthly**, the data sample did not include other industries besides the paper and ICT sectors in the printed functionality area. Some electronics companies were also very large with huge R&D budgets compared to paper and printing industry actors. The difference in the number of patents granted in the two industries may also cause discrepancies in the analysis. **Fifthly**, a systematic and wider comparison of industry transformation analysis with many industries and historical cases, as well as patent data analysis methods would provide a more solid ground to make conclusions and generalizations about the phenomenon and the role of complementary innovations in industry evolution. More reliable conclusions would have required more empirical research about the technological trajectories of the industries in convergence research.

**Sixthly**, there are some inherent limitations in using patent data for analysis. Not all innovations are patented and sometimes firms build on previous knowledge to file new patents to keep pace with their intellectual capital. There are also inter-industry and inter-firm differences in the propensity to patent, and interpreting the findings of the citation analysis requires at least minimum knowledge on patenting search procedures and reports in different countries. **Seventhly**, there are several methodological issues related to patent analysis which need to be taken into account when interpreting the results. For example, related to different patent systems, the interpretation of the results, country and industry specifics need to be taken into account (Cohen et al., 2000). All in all, one has to be very careful when interpreting the results of patent-based indicators, because there are, of course, many fundamental differences in citation practices between the US and the European patent system (Michel & Bettels, 2001). There is also the aspect of "complex product industries" as the technological complementarity or general purpose technologies are one cause for overlapping patents.

## *6.4 Suggestions for further research*

Future studies could be made at least in three different areas. **Firstly**, this study mostly evaluates technology development in converging environments and future research should address the question **how to effectively find potential converging areas from the patent data without ex ante or expert knowledge**. In the patent analysis this could mean some kind of semantic analysis where search term and technology field independent analysis can be conducted. The rigid categorization of industries (SIC), patents (IPC) and non-patent literature is one of the main challenges in analyzing the emerging fields of science and technologies. The problem of predefined and rigid categories may lead to missing emergent or dynamic phenomena in science and technology (Rafols & Meyer, 2010). Future studies could use different kinds of similarity (and diversity) indicators for the determination of similarity between the patents using e.g. text documents found in the patent abstracts (Shibata et al., 2010) or semantic sensitivity measures so that documents conceptually very close but with differing vocabulary would be identified as similar. There is also still room for further testing the IPC-based analysis and possible proxies of convergence. We see that it would be a scientifically significant contribution if the novel patent analysis methods could be used effectively to create understanding in advance about the technology development and industry convergences.

**Secondly**, further research is needed to understand more deeply the relations and interaction between different stages in the convergence or fusion process. Patent citations analysis is mainly used to evaluate technology dominated emergence of convergence. Understanding more deeply the interactions could be useful for technology and policy makers. In the framework of this thesis, there was no attempt to connect patenting and product competition, and in the test environment, technological convergence has not meant convergence in sciences (**science/technology interaction**). It seems evident that in reality the stages of convergence co-evolve and interact in rather complex ways compared to the linear model in which the progress of science was essentially exogenous and technological advances were merely the outcomes of applied research and development efforts. In the science and technology driven innovations it would be natural to think that in the long run supply factors (science, technology) are dominating in the early phases and demand factors (application, industry) in the later stages of the convergence process. Understanding more deeply the complex interaction between different stages in the convergence process would be useful for technology and policy makers helping strategic R&D management. In order to evaluate the substitution and complementary effects one challenging methodological problem is with the interaction of patents and product markets (**technology-product market interaction**). In the future studies this is best achieved in sectoral reviews that take into account the competitive interaction both in technology and product markets. The use of patent analysis methods helps to recognize trajectory changes early in the industry, but whether there is an effect in the product markets is impossible to determine only based on patent analysis as the patent literature does not contain a reliable method to map patents to products markets. The indicators of market convergence, such as product portfolios and customer trends, would provide important insights into the concrete effects of patents on product market competition. In future studies this is best achieved in sectoral reviews that take into account the competitive interaction of firms both in technology and product markets. (See Harhoff et al., 2007) It is clear that technology-based products need genuine demand to succeed, and it is impossible to know the extent of demand before new products are in the markets.

**Thirdly**, other empirical case studies of potential convergence and historical evidence collected from different intersection areas and different convergence types could provide better understanding of the phenomenon which is the precondition to making conclusions and generalizations for theoretical development and managerial interest. This could also include combining the macro and micro level perspectives, as, for example, patents have been used to analyze the macro-level paradigm shift, which would be essential in combining the changes in micro-level innovation activities in order to get deeper insight into the organization's innovation processes and management. On the macro level there are also opportunities to combine patent-based data with other databases, like alliance activity data.

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