Diving into the dynamics of product evolution: Analyzing technological discontinuities during the era of incremental change and cognitive convergence on a dominant design.

THÈSE N^{O} 7624 (2017)

PRÉSENTÉE LE 31 MARS 2017
AU COLLÈGE DU MANAGEMENT DE LA TECHNOLOGIE
CHAIRE DE STRATÉGIE ET INNOVATION D'ENTREPRISE
PROGRAMME DOCTORAL EN MANAGEMENT DE LA TECHNOLOGIE

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

POUR L'OBTENTION DU GRADE DE DOCTEUR ÈS SCIENCES

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Suisse
2017

Ich widme diese Arbeit meinen Eltern Ruth und Harald, meinem Bruder Frédéric und Lauranne.
Liebsten Dank für eure Unterstützung.

Acknowledgements

Writing the PhD thesis was an extraordinary and a special stage of life. I believe that one could compare it to a rollercoaster ride. Rollercoasters and their appearance attract various curious people. Before you get to enjoy the ride, you sit in a moving car on a track with loads of unknown turns ahead of you. You rarely comprehend these turns while inspecting the rollercoaster from the ground – but most importantly, in the end, you think it has been a hell of a ride and that you loved every minute of it (ex post). The only difference to a rollercoaster is that writing a PhD thesis requires people around you that accompany, support, help, challenge, surprise and inspire you. I would like to thank the people who have been around me during the last couple of years.

I am grateful to my advisor Chris Tucci. I remember his reaction to my request of writing a PhD thesis under his chair: “great, let’s do it”. Chris has always supported my work; he continuously expressed his trust and provided guidance from the first day of the PhD journey. Likewise, I will never forget his infectious enthusiasm and interest.

I wish to express my gratitude to my advisors Philipp Morf, Pierre Rossel and Richard Tee. I thank them for their time, commitment and valuable input. A special thanks to Gianluigi Viscusi and Heidi Gautschi for their valuable feedback and insights into the studies of the thesis. In addition, I am very grateful for Matthias Finger’s insights into qualitative research.

My PhD was a journey of balancing work at Zühlke and at the same time progressing my PhD on the never ending rollercoaster of a PhD journey. A very deep thank you goes to my former bosses Peter Spörri, Christoph Durmüller, Sven Krause, Claudia Reuter and Robert Knop who actually made it possible for me to conduct my PhD at EPFL while at the same time working for Zühlke. I am also grateful to my colleagues at Zühlke for their feedback and insights on the research topics: Claudia Reuter, Marcel Scacchi, Rolf Maisch, Christoph Dürmüller, Claudio Schödler and Martin Petruzzi.

The balancing act on the rollercoaster has only been possible with the help of people I appreciate. Special thanks to Giada and Joana for jumping on the rollercoaster ride at the same time. It was much easier with you guys at my side. Thanks to all my friends and colleagues in Lausanne: Abhik, Alan, Albina, Amin, Andreas, Claudia, Deep, Fabiana, Florian, Gianluigi, Giovanni, Heidi, Lorenzo, Mary Jean, Maryam, Merve, Mohamad, Monica, Nettra, Philipp, Reinier, Shira, Simone, Stefano, Tilo and Toni. Furthermore, I acknowledge and thank the entire community of the College of Management at EPFL (professors, colleagues, administrative staff and IT team) – Special thanks to Cyrielle and Céline.

Thanks to all my (lifelong) friends (Andreas, Christin, Corinne, Dominik, Elias, Joel, Jonas, Juan, Mélanie, Michael, Patrick, Petra, Raymond, Reto and Sebastian) in Fribourg and around it for making sure I would disconnect and relax from my work from time to time by taking me out.

Thanks to my brother Frédéric and my grand-mother Marie-Louise for their love and support. A very special thank you to my parents Ruth and Harald. Without your never ending inspiration, education and motivation the thesis would not have been possible.

Last but not least, thank you to Lauranne – particularly for your patience. You were always there when I needed it the most. Thank you for all your love and encouragement.

“All everything that I understand, I only understand because I love.” – Leo Tolstoy

Fribourg, Februar 2017

Abstract

Three distinct stages describe the technological evolution of a product over time: ferment, convergence on a dominant design and an era of incremental change. Until recently, the era of incremental change has been characterized as stable and one that involves low levels of technological innovation. However, recent studies have indicated that this era of incremental change may actually be quite disruptive. This raises the question as to which processes and mechanisms in new product development during the era of incremental change trigger high levels of innovation. First, this dissertation offers a conceptual study about how collaboration practices with suppliers characterized by a relatively high intensity shift the technological evolution away from the era of incremental change towards the stage of ferment. Second, a quantitative study of the medical technology industry in Europe reveals that involving suppliers in new product development during the era of incremental change may trigger technological novelties that are incorporated into new product architectures; A new product architecture shifts the technological evolution towards the era of ferment. According to the results of the second study, it appears that only by improving products based on established architectures are firms unable to innovate new technologies.

Additionally, the stage of convergence on a dominant design has mainly been examined on the basis of technological convergence. However, a possible convergence on a dominant design away from the stage of ferment also involves a cognitive variable. Third, the dissertation observes the cognitive variable while examining the nascent smartwatch market. Within a nascent market, firms within previously distinct domains compete with one another. Firms lack a better understanding of customer preferences and develop initial products based on assumptions that are rooted within their previous industry. This qualitative study illustrates that firms from the same prior industry conceptualize their products in a similar way with regard to nascent product features.

Overall, this dissertation more deeply explores the product life-cycle of technological development, provides a better understanding of the dynamics during the era of incremental change, demonstrates how the technological life-cycle of a product may shift from one stage to the other and supplies additional explanations concerning how a dominant design may emerge out of the ferment stage of technological development.

Keywords

industry evolution, technology life-cycle, era of ferment, cognitive convergence, era of incremental change, dominant design, supplier involvement, technological innovation, conceptual paper, qualitative method, quantitative method, medical technology, smartwatches

Kurzfassung

Der technologische Lebenszyklus eines Produkts kann in drei Phasen unterteilt werden: die Phase der Unruhe, die Phase der Konvergenz in Richtung eines dominanten Designs und die Phase des inkrementellen Wandels. Bis vor Kurzem betrachteten Forscher die Phase inkrementellen Wandels als stabil. Dementsprechend attestierten sie dieser Phase einen tendenziell tiefen Innovationsgrad. Neueren Studien zufolge kann dieses Stadium aber durchaus als dynamisch und disruptiv beschrieben werden. Daher drängt sich die Frage auf, welche Prozesse und Mechanismen während der Entwicklung neuer Produkte in der Phase inkrementellen Wandels hohe Innovationsgrade auslösen.

Die vorliegende Dissertation bietet einerseits eine konzeptionelle Analyse und untersucht, inwiefern eine intensive Zusammenarbeit während der Produktentwicklung die technologische Evolution eines Produkts beeinflusst. Die Untersuchung führt zu der Erkenntnis, dass intensive Kooperation den technologischen Lebenszyklus eines Produktes weg von der Phase inkrementellen Wandels hin zur Phase der Unruhe verlagert. Andererseits gibt eine quantitative Studie Einblicke in die europäische Medizintechnik und behandelt die Frage, inwiefern Lieferanteneinbezug während der Produktentwicklung als Auslöser für technologische Neuerungen gesehen werden kann. Die Resultate der quantitativen Studie zeigen, dass technologische Neuerungen in eine neue Produktarchitektur integriert werden. Eine neue Produktarchitektur verschiebt den technologischen Lebenszyklus in die Richtung Phase der Unruhe. Zusätzlich deuten die Ergebnisse der quantitativen Studie darauf hin, dass Firmen, die ihre Produkte auf Basis einer etablierten Produktarchitektur weiterentwickeln und verbessern, oftmals nicht in der Lage sind, technologische Innovationen einzuführen.

Darüber hinaus ist bekannt, dass Konvergenz in Richtung eines dominanten Designs eine technologische und kognitive Variable beinhaltet. Die Konvergenz in Richtung eines dominanten Designs wurde hauptsächlich aufgrund technologischer Konvergenz studiert. Eine dritte, qualitative Studie analysiert die kognitive Variable, indem der im Entstehen begriffene Smartwatch-Markt untersucht wird. In diesem neuen Produktmarkt befinden sich Firmen, die zuvor einen anderen Produktmarkt bedienten, nun in einer Konkurrenzsituation. Kundenwünsche sind in einem solchen Markt noch nicht bekannt. Daher entwickeln Firmen erste Produkte auf der Basis von Annahmen, die im früheren Markt ihre Wurzeln haben. Die qualitative Studie veranschaulicht, dass Firmen desselben vorherigen Marktes ihre Produkte für den neuen Smartwatch-Markt hinsichtlich Produktfunktionalitäten auf eine ähnliche Weise konzeptualisieren.

Diese Dissertation erforscht übergreifend den Produktlebenszyklus der technologischen Entwicklung, bietet ein besseres Verständnis der Dynamik während der Phase des inkrementellen Wandels, zeigt, wie sich der technologische Lebenszyklus eines Produkts von einer Phase in eine andere verschieben kann und liefert zusätzliche Erklärungen darüber, wie ein dominantes Design aus der Phase der Unruhe hervorgehen kann.

Stichworte

Industrieentwicklung, Technologielebenszyklus, Unruhe der Gärung / Unruhe, kognitive Konvergenz der Technologien, Phase des inkrementellen Wandels, dominantes Design, Lieferanteneinbezug, technologische Innovation, konzeptioneller Aufsatz, qualitative Methoden, Medizintechnik, Smartwatches

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Chapter 1 Introduction

The technology of a product evolves over time according to the life-cycle model of technological evolution (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). This model examines the dynamics of product evolution over time (Murmann & Frenken, 2006). According to this model, there are three distinct stages of technological progress: the ferment stage, the convergence on a dominant design stage and an era of incremental change. Figure 1 illustrates the life-cycle model of technological evolution.

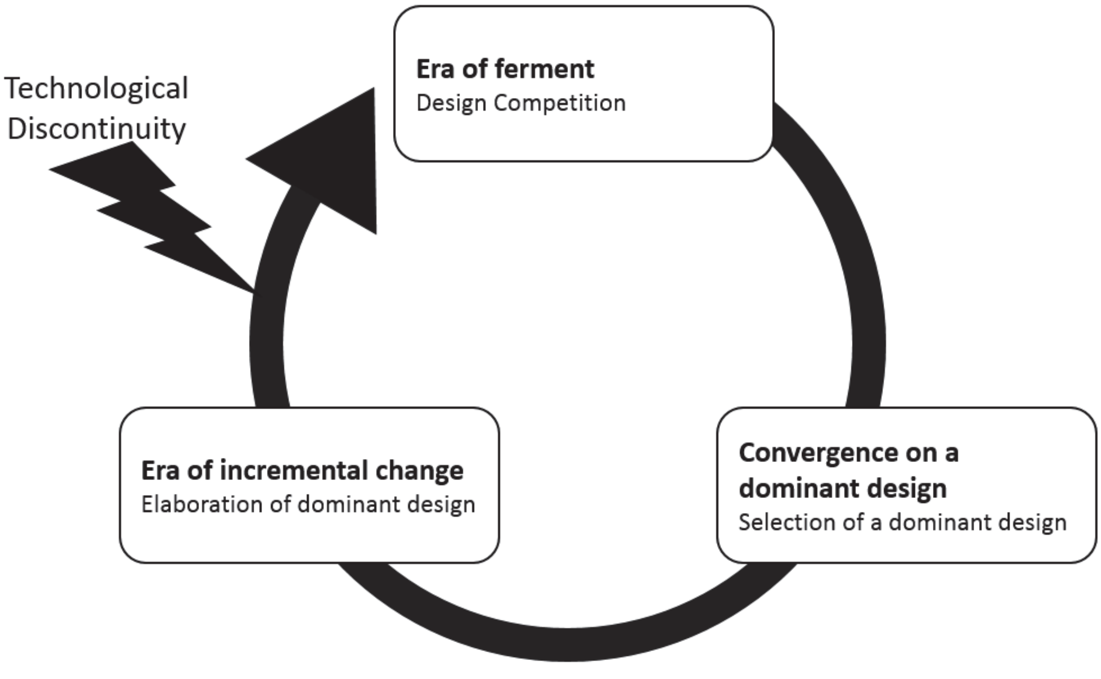

Figure 1: The Technology Cycle (Anderson & Tushman, 1990).

The early ferment stage is characterized by changing and fleeting product characteristics, market boundaries and user needs (Aldrich & Fiol, 1994; Clark, 1985; Lounsbury, Ventresca & Hirsch, 2003; Santos & Eisenhardt, 2009). However, the comprehension of industry stakeholders (e.g. customers, producers, critics and regulators) is changing and remains unclear (Kennedy, 2008). Furthermore, potential customers have little or no experience with the product and their preferences are therefore, unformed and unarticulated. Chesbrough and Kusunoki (2001) have characterized this phase as the integral phase of technological evolution. However, uncertainties about the product design exist; Indeed, how product components are linked together remains unclear to a large degree. Thus, market and technological uncertainties result in a diversity of product designs (Abernathy & Utterback, 1978; Dosi, 1982; Lee et al., 1995; Smith, 1997; Utterback, 1994). In this way, various firms that compete within the same market devise different product designs that involve varying components and interfaces.

Eventually, competing alternatives may converge on a dominant design. A dominant design is a standard set of technologies and interfaces and represents a design that is based on a shared understanding of which performance attributes are important (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). A dominant design is further superior to other competing designs (Suarez & Utterback, 1995) and converges only when the design reflects both technological and cognitive convergence (Clark, 1985). While technological convergence marks a consensus about a set of standard technologies, modules and interfaces (Abernathy & Utterback, 1978; Anderson & Tushman, 1990), cognitive convergence is characterized by a common understanding of what the product is, how the product may be used and what core attributes will have value (Kaplan & Tripsas, 2008).

The era of incremental change marks a point in time when uncertainty regarding product architecture is reduced. During this time, the linkages between components are standardized and the components themselves remain stable. Chesbrough and Kusunoki (2001) have characterized this phase as the modular phase of technological evolution. During this phase, there is a stable mapping of functionalities to components (modules) and stable interfaces between the components. Firms may mix and match components with one another for increased flexibility in configuring the end products; The type of technological innovation shifts to lower component levels (Anderson & Tushman, 1990; Murmann & Frenken, 2006). Moreover, firms adapt their locus of product innovation on manufacturing processes, cost reduction and customer segmentation (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Henderson & Clark, 1990). The era of incremental change is characterized by relative stability and incremental innovation until a subsequent technological discontinuity (Dokko, Nigam & Rosenkopf, 2012; Jaegul Lee & Berente, 2013), such as an innovation. This innovation may invent a new technological cycle that moves from an established dominant design towards the era of ferment. Thus, a new dominant design may emerge (Garud, Kumaraswamy & Langlois, 2002).

1.1 Motivation

While existing research that focuses on the era of incremental change has argued that this phase is rather stable (Jaegul Lee & Berente, 2013), recent work has demonstrated that the era of incremental change is relatively dynamic and interesting (Funk, 2009; Jaegul Lee & Berente, 2013). For example, an incremental component innovation may be a source of a technological discontinuity that in turn, may lead to disruptive innovations. Such disruptive innovations could then shift the technological life-cycle from the era of incremental change towards the era of ferment. However, a better understanding of what processes and mechanisms in new product development during the era of incremental change trigger a technological discontinuity is lacking.

We know that a well-established product architecture during the era of incremental change facilitates innovation on the component level in terms of incremental and modular innovation (Henderson & Clark, 1990). However, if a firm only innovates on the basis of an established architecture it may not achieve breakthrough innovation, since such products only provide limited differentiations (Robertson & Ulrich, 1998). Conversely, we know that designing products that allow components to be mixed and matched facilitates supplier involvement in new product development (Furlan, Cabigiosu & Camuffo, 2013), which in turn, increases the innovativeness of products (Sun, Yau & Suen, 2010). These contrary implications on the innovativeness of new products need to be analyzed in more detail (Furlan et al., 2013; J.H. Mikkola, 2006; Stanko, Molina-Castillo & Harmancioglu, 2015).

The eventual convergence on a dominant design is a twofold process that incorporates both a technological and cognitive variable (Clark, 1985). Scholars have mainly focused on a potential convergence on a dominant design on the basis of technological development (Murmann & Frenken, 2006). For example, Henderson and Clark (1990) have identified the example of a portable, transistor radio receiver as a type of innovation that changes the product's architecture, but leaves the components unchanged. Additionally, we do not know how a firm's previous industry membership influences the conceptualization of product features. Different firms with different backgrounds play an important role in many new industries (Martin & Mitchell, 1998). Scholars have mainly studied variations in resources and capabilities and how such differences explain varying strategic behaviors within a nascent product market (Klepper & Simons, 2000).

1.1.1 Scope and Objectives

This dissertation explores the life-cycle model of technological evolution (Abernathy & Utterback, 1978; Anderson & Tushman, 1990) in different contexts and applies different methods.

The first conceptual essay builds on the literature on product modularity to illuminate processes and mechanisms of the era of incremental change of the product life-cycle of technological development (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). Principles of product modularity are applied during the era of incremental change, and seem thus appropriate.

Essay two (Chapter 3) is a quantitative study on the innovative capacity of modular design principles during the era of incremental change among medical technology companies in Europe. This industry uses sophisticated technologies and invests in innovative solutions (Department of Commerce, 2009; Dümmler & Willhalm, 2008; Hofrichter & Dümmler, 2014; Medical Cluster, 2015; TÜV SÜD, 2016). Exploring innovation within this industry appears to be reasonable.

Essay three analyzes how a dominant design may emerge out of the ferment stage of dominant designs. The study conducts a qualitative research on the basis of semi-structured interviews and secondary data (Popay, Rogers & Williams, 1998) among nascent smartwatch producers.

1.1.2 Overview of the Dissertation

This section gives a brief overview on the three essays of the dissertation.

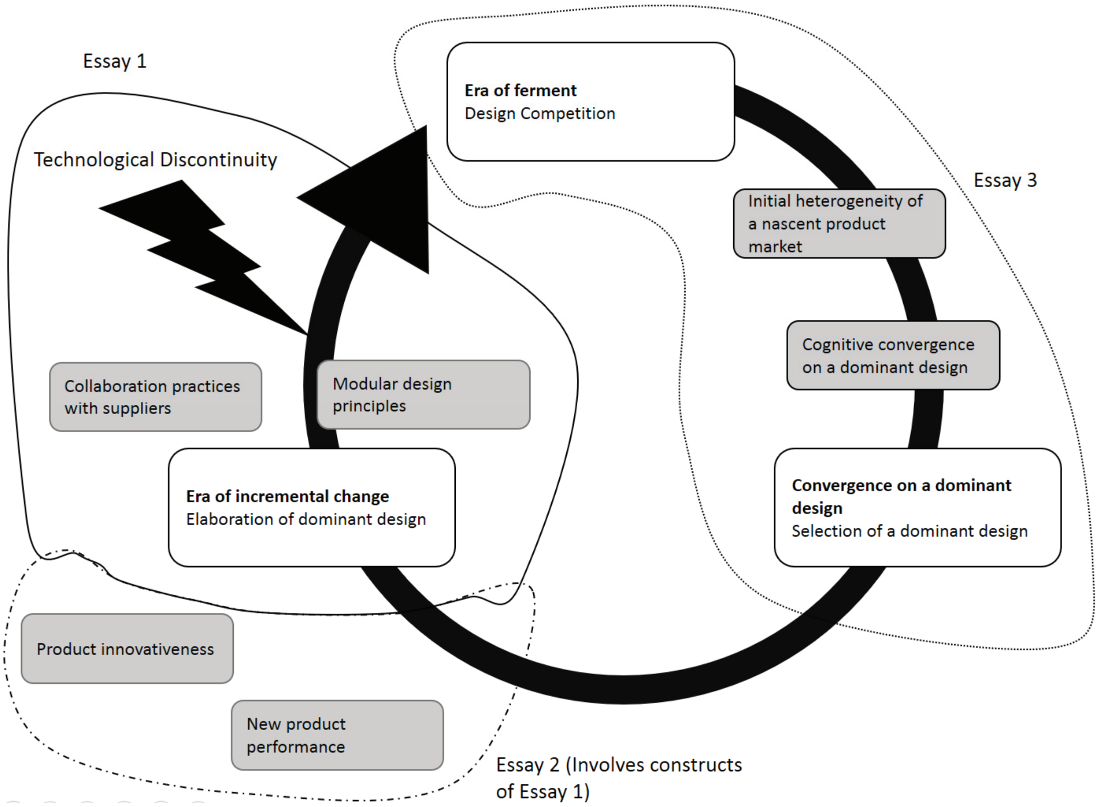

Figure 2: Overview of the dissertation

Figure 2 summarizes the main constructs of each essay of the dissertation. Both essay one and two focus on the era of incremental change. Essay three is concerned with the era of ferment and the subsequent convergence on a dominant design.

Essay one (Chapter 2), a conceptual paper based on a literature review, reviews the emergence of modular design principles from research on complexity. Modular designs are characterized by the relatively high degree to which a system's components can be divided and re-combined with one another (Schilling, 2000). This essay further discusses how collaboration practices with suppliers, while applying modular design principles, trigger a technological discontinuity that shifts the technology back towards the era of ferment. Thus, insight into how a shift towards the stage of ferment unfolds is important for improving our understanding of how technology evolves, and more broadly, how industries evolve.

Essay two (Chapter 3) examines what implications the dynamics between modular design principles, supplier involvement and product innovativeness have on the progress of the product life-cycle of technological development. This essay further develops a model that measures (1) the extent to which firms apply modular design principles, (2) the extent to which they involve suppliers in new product development, (3) the innovativeness of a new product (4) and the extent to which a new product is financially successful on the market. Similar to the first essay, examining the interrelationships between these variables provides interesting insight into how technology progresses across the product life-cycle of technological development.

Essay three (Chapter 4) examines how the previous industry memberships of nascent smartwatch producers affect the decision on the conceptualization of early smartwatch functionalities. Executives of the same prior industry similarly assume how customers will use the product and what features will be successful. Indeed, discussions on the initial heterogeneity of nascent product features led to insights into how assumptions about customer needs and usages influence the decisions regarding the ultimate design of the smartwatch. Thus, examining the initial heterogeneity of assumptions about customer needs and how these influence initial product features improves the understanding of how a dominant design may emerge on the basis of the cognitive variable of an eventual convergence on a dominant design (Clark, 1985).

Chapter 2 How Industry Evolution Unfolds: Insight into Modularity on the Organizational and Knowledge Levels

2.1 Introduction

Modularity was first introduced in Simon's (1962) essay on complex systems. A complex system consists of numerous parts, each of which serves a specific functionality (or multiple functionalities) and interacts with one another in a complicated manner. Simon’s (1962) article has provided the central ideas for examining the properties of complex systems and defining design principles for such systems. He has further argued that complex systems perform better if they have hierarchical and decomposable structures, citing examples of such structures within physical, chemical, biological, social and artificial systems. This paper, however, only focuses on the development and manufacturing practices of physical systems, such as products.[1] Since the 1990s, many scholars have contributed to the research on modularity and acknowledged that it is a design principle for complex products (Campagnolo & Camuffo, 2010). Indeed, it is a continuous concept that characterizes the extent to which components of a product can be “separated and recombined” (Schilling, 2000, p. 312) as well as mixed and matched. A high degree of modularity allows for a high degree of separation and recombination. Only a small number of components are completely inseparable and thus, cannot be recombined; Components of many products are coupled with each other to some extent (Schilling, 2000). Thus, it can be said that a majority of products are modular to some degree.

In a relatively modular product, one or only a small number of a product’s functions are allocated to physical components (Ulrich, 1995). Moreover, in a less modular product, many functions are mapped to one physical component. The architecture of the product defines which functions are mapped to which physical components as well as the interrelation between components through standardized interfaces (Ulrich, 1995). Extant research has revealed that manufacturers are likely to outsource the development and production work of components along standard interfaces. In such a case, the division of labor for product development refers to the degree of modularity – suppliers develop, produce and deliver components consistent with their technical skills and competences (Campagnolo & Camuffo, 2010; Chesbrough, 2005). However, two streams of literature have sug-

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[1] However, some ideas might be applicable for other applications.

gested different implications of suppliers being responsible for component development and production. The first stream has suggested that decomposing and outsourcing the development tasks facilitates parallel and independent development of the components (Campagnolo & Camuffo, 2010; Colfer & Baldwin, 2016; Sanchez & Mahoney, 1996). Researchers who support this implication have argued that standardized interfaces provide a form of intrinsic coordination – suppliers may concurrently and automatously develop components. For example, manufacturers of automobiles often rely on independent suppliers to obtain already assembled and tested modules, such as doors or cockpits, that were developed and produced in a parallel and independent manner (Camuffo, 2004). The standardized interface allows for a form of independency that seems to decrease the need to coordinate the suppliers' development and production work. Conversely, the second stream of literature has suggested that the manufacturers of modular products continue to engage in tight collaboration practices with their component suppliers (Brusoni & Prencipe, 2001; Brusoni, Prencipe & Pavitt, 2001; Colfer, 2007; Hoetker, 2006; Staudenmayer et al., 2005; Takeishi, 2002). Indeed, manufacturers engage in coordination activities and share component knowledge for successful product development. Decomposing and outsourcing development tasks does not facilitate parallel and independent development of the components. Although there are standardized interfaces, interdependencies between the components require that the coordination be managed, that there be managerial authority for supplier relationships and that knowledge about component technology be maintained. For example, the interdependencies of components within the software, electronics, telecom, photography and publishing industries require manufacturers to coordinate and control relationships with component suppliers (Staudenmayer et al., 2005). The second stream of literature has found evidence of relatively tight cross-company interaction for technologically sophisticated products. Standardized interfaces, decomposing and outsourcing component development and production and the aforementioned supplier involvement practices all describe new product development characteristics during the modular phase of technological development (Chesbrough & Kusunoki, 2001). Scholars have also referred to the era of incremental change (Abernathy & Utterback, 1978; Anderson & Tushman, 1990) while describing characteristics of the modular phase of technological development. Similarly, the era of incremental change is characterized by reduced uncertainty in product architecture – linkages between the components are standardized and the components themselves remain stable.

2.2 Research Gap

Existing work that has primarily focused on the modular phase (Chesbrough & Kusunoki, 2001) of technological development typically characterizes this period in terms of stability and minimal innovation (Anderson & Tushman, 1990; Murmann & Frenken, 2006). The product architecture remains stable and companies focus their innovation activities on manufacturing processes, cost reductions, component improvements and customer segmentation (Abernathy & Utterback, 1978;

Anderson & Tushman, 1990; Henderson & Clark, 1990). However, more recent research has indicated that the modular phase is relatively dynamic and interesting (Funk, 2009; Jaegul Lee & Berente, 2013). For example, incrementally improving existing components may trigger a change in product architecture, which in turn results in disruptive innovations (Funk, 2009). A change in the established product architecture subsequently shifts the technology towards the stage of ferment of technological development, which is characterized by changing and fleeting product characteristics, user needs and market boundaries (Aldrich & Fiol, 1994; Santos & Eisenhardt, 2009). Chesbrough and Kusunoki (2001) have referred to the integral phase while describing the era of ferment. Similar to the era of ferment, during the integral phase, technology is not well understood, overall comprehension of how the parts of the product interact with one another is lacking and manufacturers cannot effectively specify their product requirements to suppliers.

The shift from the modular to the integral phase changes the product architecture and is characterized by architectural innovation (Henderson & Clark, 1990). However, how various components are connected and interact with one another remains, to a large degree, unclear after innovation in the product architecture, especially since it is uncertain how the new product architecture is firms have to integrally (holistically) rethink the overall architecture and gain knowledge about the new architecture (Chesbrough & Kusunoki, 2001). The term integral refers to how companies must reconsider their product architecture, either integrally or holistically. Indeed, they must question the architecture of the entire product. We lack a better understanding of which characteristics in new product development during the modular phase trigger higher levels of innovation – in the form of breakthrough innovations that may change the established product architecture. In particular, we know little about how organizational structures and knowledge management in product development during the modular phase trigger innovations in product architecture, which in turn shifts the technology towards the integral phase. It is critical to understand the mechanisms that trigger this shift towards the integral phase, since this shift forces firms to adapt their organizational structures and knowledge management in new product development. After a shift, the manufacturing firms must adapt to the new architectural design. Furthermore, organizational structures in product development that are characterized by intensive collaboration and intense knowledge sharing become, to some extent, obsolete (Chesbrough & Kusunoki, 2001). Insight into how a shift towards the integral phase unfolds is important for improving our understanding of how technology evolves, and more broadly, how industries evolve.

Within this paper, I address this gap by exploring how organizational structures for modular product design trigger a shift. Organizational structures during the modular phase are likely to be of significance due to their innovative capacity. Proactively involving suppliers early on during the concept exploration and definition stages of product development projects and remaining knowledgeable in component technology may result in product innovations that ultimately change the product architecture (Bozdogan, Deyst, Hoult & Lucas, 1998).

This chapter is structured as follows: I begin by briefly reviewing the emergence of modularity from research that has been conducted on complex systems. Subsequently, I discuss the limitations and properties of modular product design and examine the organizational structures and knowledge management principles related to the modular phase. Furthermore, I discuss the organizational structures and knowledge management used during the integral phase. I also discuss how organizational structures may trigger innovation, which shifts the technology towards an integral phase. Finally, I suggest possible avenues for future research.

2.3 Modularity Stems from Research on Complex Systems.

Simon's (1962) illustration of general design principles and properties is a common starting point when analyzing complex systems (Ethiraj & Levinthal, 2004). A complex system is one that consists of many parts, each of which have a specific functionality and interact with one another in a complicated way. Given the characteristics of the functioning parts and the definition of the interaction between these parts, such a system generates an output that is more than merely the sum of the outputs of its parts. Furthermore, the overall system output can only be achieved when the entire system works properly. Another property of complex systems is that the overall system is divided into subsystems and the subsystems themselves may further be divided into sub-subsystems. Simon has argued that complex systems perform better if they have such hierarchical and decomposable subsystem levels. In biological systems, for example, cells are synthesized into tissues, tissues into organs and organs into systems (Simon, 1962). Within the context of this study, however, hierarchy is observed as a phenomena found within firms, governments or universities, all of which have a clearly visible subsystem structure. Accordingly, we see that complex systems appear to be beneficial when they are organized in hierarchical forms (Alexander, 1964).

Modularity is an attribute of complex products that favors hierarchical design structures and defines the number of subsystems, the levels of subsystems and the interdependence between them (H. Simon, 1962). Modularity tries to decrease the interdependence between subsystems and subsequently, increase the interdependence within subsystems (Baldwin & Clark, 1997). The number of subsystems and parts is a function of the system’s complexity. Pragmatically, complexity depends on the level of detail required to describe a system, including the subsystem levels: The more detail and hence, information necessary to describe a system, the more complex it is (Bar-yam, 2003).

Modularity has been used as a design strategy since the 1990s (Henderson & Clark, 1990; Ulrich & Tung, 1991). Since then, many scholars have contributed to the research on modularity and furthermore, have agreed with Schilling (2000) that it is a continuum that characterizes the level to which a system's components can be divided and combined. Sanchez and Mahoney (1996) have revealed that the specification of interfaces permits a range of functional or physical variations in any given component without requiring changes to the overall product design or to the design of the other components. The better the compatibility of the components, the better the joint functioning of the components; This defines the overall performance of a product (Garud & Kumaraswamy, 1995; Henderson & Clark, 1990; Sanchez, 1995; Sanchez & Mahoney, 1996; Schilling, 2000). For example, a watch includes hands that display at least the hour and minute as well as the second. Thus, we allocate the separate functions of displaying the hour, minute and second to the corresponding clock-hands, while the clock face displays the overall time. Only the combined presence of the three clock hands and the face allows for joint functionality; Displaying the time is the overall joint functionality of a watch. The sets of components of the clock face and the clock hands are compatible with each other and can be recombined according to the rules of the product architecture. As a result, a watch manufacturer may produce hundreds of different watch models by assembling the models using different combinations of standard components (Pine, 1992).

Building upon subsystem theory, Baldwin and Woodard (2008), Boer (2014) and Sanchez and Mahoney (1996) have all provided insight into the importance of decomposing a complex product into subsystems to improve a firm's effectiveness for building and organizing complex products. Watch faces, -hands and -wristbands can be divided across a group of people that can work independently and in parallel to develop a subsystem that reduces development time (Baldwin & Clark, 2000; Parnas, 1972; Sanchez, 1995; H. Simon, 1962). Components that may be mixed and matched allow a company much more flexibility in configuring the end products (Sanchez, 1995; M. Schilling, 2000; Worren, Moore & Cardona, 2002), making it easier to upgrade, improve or customize a product for a specific customer group. Furthermore, leveraging core components across products enables an organization to reduce the costs of differentiating (Sanchez & Mahoney, 1996) and thus, reduce the time to market (Ernst & Kamrad, 2000). Additionally, it is associated with an increases in the number of product configuration possibilities available for customers (Schilling, 2000), since heterogeneous customers do not agree on a single configuration. Indeed, modularity allows a heterogeneous customer to choose a product configuration that better fits their product requirements (Jacobs, Droge, Vickery & Calantone, 2011; Schilling, 2000).

2.4 Examples of When a Less Modular Product Architecture is Advantageous

In contrast to a modular product, a regular product requires changes to every component when a change is made to a single functional element (Ulrich, 1995). However, there are cases in which a less modular product architecture is advantageous. For example, in cases where a system should have a relatively high acceleration that is dependent on mass, aerodynamics, size and shape. Components require space, have a certain volume and are composed of material with mass and additional physical properties. In this case and in many other cases, increasing the overall product performance usually involves minimizing the volume and weight of the product. Thus, in order to decrease volume and weight, designers map several functions to one component and additionally try to tightly couple the components (Ulrich, 1995).

Another example is in the case of high performing motorcycles (Ulrich, 1995). The mapping of several functions to one component makes it possible to decrease the mass of the motorcycle. Conventional motorcycles have a steel tubular frame that is separated from the transmission and engine. For high performing motorcycles, the transmission and motor case form the structure of the motorcycle. However, there is no steel tubular frame in the conventional motorcycles that forms the structure of the motorcycle. The sharing of functions of one component creates a less modular architecture and decreases the mass of the product, which in turn increases the motorcycle’s performance in terms of acceleration and speed.

Moreover, while studying the bicycle drivetrain industry, Fixson & Park (2008) have found that the drivetrains changed from relatively modular to less modular. This adaption to more integration occurred because the drivetrains required a superior overall product performance due to shifting user applications.

Furthermore, components are coupled to minimize volume. Celona, Embry-Pelrine and Hölttä-Otto (2007) have revealed that less modular products require less space than relatively modular products, such as phones, computers, cassette players and CD players. In order to decrease the volume of a product, designers couple the components and develop less modular products. Minimizing the size and mass also minimizes unit production cost for high-volume products. When production volume increases, the cost of material also increase and becomes more important (Ulrich, 1995). Therefore, less modular designs are chosen because they have lower unit costs.

Finally, modularity may also have a negative impact on innovation. Designing new modular products may be associated with developing highly similar products and only limited differentiation in new products (Robertson & Ulrich, 1998), since engineers of modular products may overly concentrate on improving components rather than trying to improve the overall product (Ethiraj & Levinthal, 2004). Another point to consider is that designers use past experience, past international standards and past compatible interfaces to define a modular product architecture, thus hindering innovativeness (Shapiro & Varian, 1999).

2.5 Design Structure Matrices

Creating a relatively adequate modular product design is not an easy task. Firms should apply modular design principles to products that they understand relatively well (Henderson & Clark, 1990; Schilling, 2000; Ulrich, 1995). Developing architectural knowledge that may encompass various technologies integrated into one product is both time consuming and cost intensive. Design structure matrices may help to conceptualize distinct modular design alternatives as well as develop a robust understanding of the product's architecture (Baldwin & Woodard, 2008; Colfer & Baldwin, 2016). A design structure matrix is a visual representation that supports analyzing various design options by structuring the knowledge of involved technologies and the corresponding system and component performance outcomes. Typically, a two-dimensional matrix is used to represent the structural or functional interrelationships of objects, tasks or teams (de Weck, 2012). Design structure matrices may group elements according to their membership within a module or team. Table 1 displays a design structure matrix that groups elements according to their relation to a module. Three elements were assigned to the two modules. Element one, two and three were assigned to one module and elements four, five and six were assigned to the other module. Such matrices help control for the emergence of system behavior, modify the system with minimal disruption and increase system robustness, *inter alia* (Browning, 2012).

However, experimentation and trial and error still remain promising means to achieve an acceptable product design (Baldwin & Clark, 2000; Chesbrough & Kusunoki, 2001).

Table 1: A 6x6 design structure matrix. The circles represent a direct relationship (e.g. dependency or a flow of information) among two elements.

	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6
Element 1	1	o				
Element 2	o	2	o			
Element 3	o	o	3		o	
Element 4				4	o	o
Element 5				o	5	o
Element 6		o			o	6

2.6 Product Architecture, Knowledge Management and Collaboration Practices Across the Modular and Integral Phase of Technological Progress

Figure 3 briefly describes the overall structure of the remainder of this essay. The next section describes knowledge management and collaboration practices during the modular phase of technological development. In terms of technology, the modular phase is characterized by well understood components and the interdependencies between them (Chesbrough & Prencipe, 2008). Subsequently, the essay describes the properties and implications of a shift from the modular to the integral phase that is characterized by an architectural innovation (Henderson & Clark, 1990). This shift changes the overall product architecture and is illustrated by an arrow placed between the “organizational structure” box and the “product architecture” box during the integral phase in Figure 3. The research follows by illustrating organizational structures and knowledge management practices during the integral phase of technological development. During the integral phase, technology is not well understood. Indeed, how the components interact remains unclear. Finally, this essay illustrates how a shift from the modular phase towards the integral phase is triggered by organizational structures that are valuable for the modular phase.

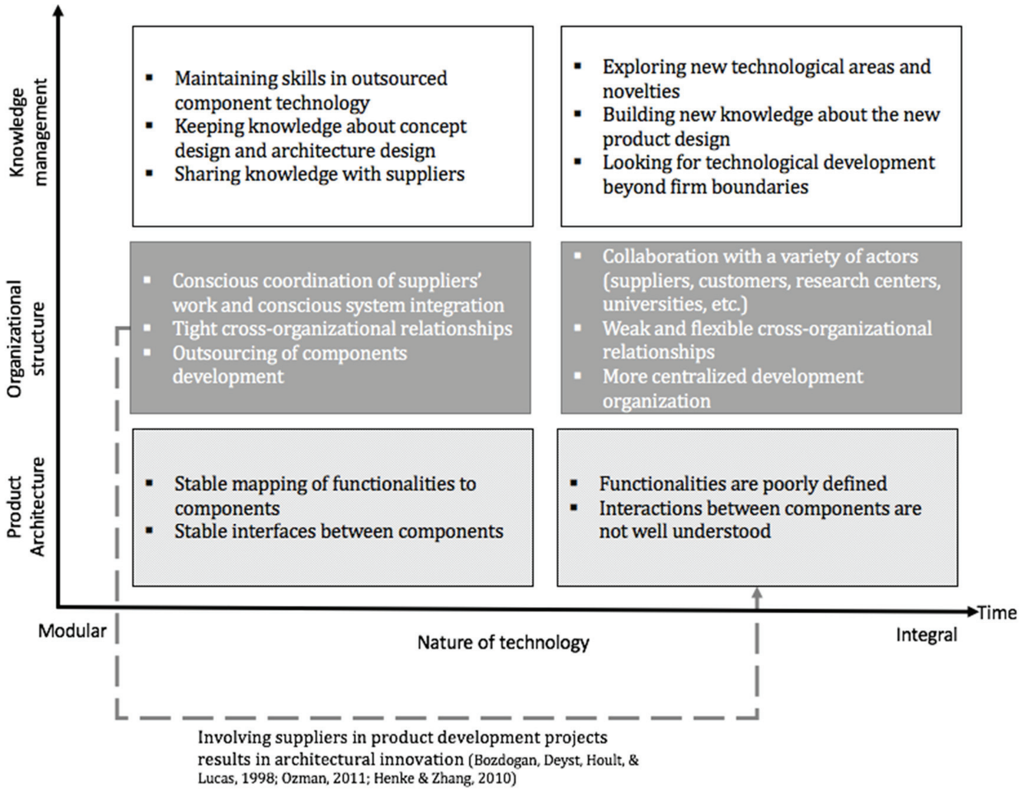

Figure 3: Changing architecture, organizational structure and knowledge management across the modular and integral phase of technological development. The framework includes the following literature additionally to the mentioned literature in the figure: Brusoni & Prencipe, 2001; Brusoni et al., 2001; Chesbrough, 2005; Chesbrough & Kusunoki, 2001; Chesbrough & Teece, 1996; Furlan et al., 2013; Granovetter, 1973; Henderson & Clark, 1990; March, 1991; Ozman, 2011; Prencipe, 1997, 2004; Staudenmayer et al., 2005; Takeishi, 2002.

2.6.1 Organizational structures and knowledge management during the modular phase

The nature of a task and the existence of a competitive environment shape an organization's knowledge and its information-processing capabilities (Lawrence & Lorsch, 1968). Cyert and March (1963) have argued that knowledge about the technical and commercial nature of a task may be located anywhere and that this location becomes the ad hoc center of authority and communication. This implies that, depending on how an organization defines its development structure (including supplier integration practices), it defines where and what knowledge is built.

Within the modular phase, interdependencies between the components are well understood and established. Indeed, a standard set of technologies and interfaces have been defined by Chesbrough and Prencipe (2008). The emergence of such an established architecture is characterized by a dominant design that marks a point in time when firms agreed about what performance attributes are important as well as on a particular product architecture (Abernathy & Utterback, 1978; Anderson

& Tushman, 1990; Clark, 1985). Once a dominant design has been established, technological evolution improves the components within the established architecture (Henderson & Clark, 1990).

2.6.1.1 Organizational structure

Companies are currently being built around stable product architectures (Brusoni & Prencipe, 2001). If a manufacturer outsources the development and production of a certain component of a product that has achieved a form of established architecture, then the required component knowledge reflects the scope and depth of the supplier's core competencies, from which the manufacturer profits (Campagnolo & Camuffo, 2010). Furthermore, if the manufacturer outsources the development of several components and more than one manufacturer develops a certain type of a product, then these manufacturers will also outsource some of the development work. Thus, creating a network of organizations with distinct knowledge about component technologies. Such an industry is characterized by interfirm modularity (Baldwin & Clark, 2000; Schilling, 2000). In such an industry, the responsibilities of designing and developing the various product components are distributed across different firms. Since suppliers are better at allocating resources to specific component technology, they have more specialized development and production knowledge. Moreover, the manufacturers that act as system integrators for fabricating the sophisticated product require conscious coordination at the organizational and component levels (Brusoni & Prencipe, 2001). Furthermore, conscious coordination of the suppliers' work requires tight-knit, cross-organizational relationships. Staudenmayer et al. (2005) have found that these interdependencies require the coordination to be managed as well as the external relationships to be controlled. Furlan, Cabigiosu and Camuffo (2013) have suggested that outsourcing components of modular products continues to require information sharing for high rates of change in component technology. Product modularity only is associated with a decrease in the need for information sharing in the presence of low rates of change within component technology. Brusoni and Prencipe (2001) have further argued that engineering knowledge is far from modular and that technological component integration is not a matter of mixing and matching readily available components.

2.6.1.2 Knowledge management

Brusoni, Prencipe and Pavitt (2001), Brusoni and Prencipe (2001), Prencipe (1997) and Takeishi (2002) have found that manufacturers of modular products who outsource development work to their suppliers maintain skills in outsourced component technology to manage the interdependencies of component development. Brusoni et al. (2001), for example, have suggested that manufacturers of aircraft engines who outsource detailed design and manufacturing maintain in-house concept and architecture design so as to successfully integrate components and monitor technological development. The gained technological knowledge helps them coordinate the work of the development units and the suppliers involved in the development process. Additionally, it helps them remain knowledgeable in various technological fields. Takeishi (2002) has also found that automakers with greater knowledge about component technology can evaluate and integrate components more effectively than firms with little component knowledge, even under a modular design process.

However, other studies have argued that there is often a perfect fit between product components and the corresponding knowledge distribution (Campagnolo & Camuffo, 2010). Colfer and Baldwin (2016) have developed the mirroring hypothesis, which predicts that there should be a correspondence between the dependencies in the technical architecture of a complex system and organizational ties between the system's developers. This hypothesis argues that modular product architecture allows for a form of intrinsic coordination, reducing the managerial authority needed to achieve successful coordination. Therefore, concurrent and automatous development of the components becomes possible, in agreement with Baldwin and Clark (1997), Sanchez and Mahoney (1996) and Schilling (2000). Colfer and Baldwin (2016) have further found that 74%[2] of the cases studied support their hypothesis. However, several studies have suggested that traditional views on the mirror hypothesis tend to be overly simple and general (Argyres, Bigelow & Nickerson, 2015; Brusoni & Prencipe, 2001; Colfer, 2007; Furlan et al., 2013; Hoetker, 2006; Staudenmayer et al., 2005).

2.6.1.3 Communication channels, information filters and problem solving

For firms that develop modular products, communication channels, information filters and strategies for problem solving refer to architectural knowledge (Henderson & Clark, 1990). For example, as a stable architecture evolved for electric cars, successful companies began to organize their structure according to the product architecture. The organizational structure is organized around the product's key components, since they are the key tasks of the design problem (von Hippel, 1990). Communication channels between these departments reflect the knowledge of the critical interactions between the components; Regular meetings are held to exchange information between the departments. Information filters are also developed according to the product architecture. Filters help immediately identify what is most crucial within an information stream (Daft & Weik, 1984). Firms' filters embody parts of the knowledge that concern key relationships between components of the technology. For example, discussions among the designers of electric motors, power split devices, generators and internal combustion engines likely change over time since they are able to identify the main part

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[2] Their sample amounts to 102 development projects. In the first set of exceptions, firms with rich organizational ties develop a modular system with many independent components. Projects of this set require prior knowledge of all implicit or potential dependencies within the technical system to be explicitly modularly designed. This is in accordance with Henderson and Clark (1990), who have suggested that building a modular product architecture requires knowledge about the core design concepts, the integration of the concepts into components and how the components are integrated. In the second set of exceptions, independent and dispersed firms without rich organizational ties develop interdependent systems or subsystems together. Their theoretical explanation is threefold: the development teams did not have enough resources and were required to access capabilities or resources they did not have, firms could expect good faith and were protected from harm and have common ground regarding how to codify and interpret product design information and what channels and protocols to use for exchanging and discussing design information.

of the critical interactions between the components. Indeed, they begin to ignore irrelevant information. Finally, firms possess a strategy for problem solving that embodies what they have learned about solving problems within their architectural framing: They no longer conduct detailed analyses or conscious execution, but apply patterns of problem solving that have been useful in solving prior problems that were reflected within the product architecture. In this way, over time, an engineer learns the most effective way to design a more efficient car and mainly focuses on the relationships within the drive system. Thus, routines in completing recurring tasks start to become increasingly more important (Daft & Weik, 1984; Nelson & Winter, 1982).

In summary, the implications of modularity for organizational structures and knowledge management reveal that while manufacturers outsource development tasks of specific components, they also engage in the management of coordination and knowledge sharing activities for the development of technological products. Indeed, companies develop communication channels, information filters and strategies for problem solving that reflect the architectural knowledge of key relationships between the components. However, technology does not remain in a steady state, but develops in cycles (Chesbrough & Kusunoki, 2001). The cycles consist of an integral and a modular phase and typically shift from the modular phase to the integral phase, but may also shift back to the integral phase (Chesbrough & Kusunoki, 2001; Chesbrough & Prencipe, 2008). A shift in the technological phase implies changes to the product architecture, i.e. in the way a product's components interact with one another.

2.6.2 Architectural innovation

A shift in a technological phase changes the way functional elements are mapped to physical components and also change the interfaces between the components[3] (Henderson & Clark, 1990). The shift from the modular phase towards the integral phase is characterized by architectural innovation. However, this reconfiguration does not mean that existing components are untouched by architectural innovation. Often a modification to a component or new radical component technology creates new interfaces and interactions with the original components in the established product (Chesbrough & Kusunoki, 2001). Architectural innovation requires the coordination be managed, that significant changes and adaptions be made to other components and that information be exchanged and shared continuously across the development teams, since architectural innovation changes the interfaces of the entire product. After architectural innovation, firms must learn from and accumulate both holistic and integral knowledge about new interdependencies and interactions between the components within the overall product (Chesbrough & Kusunoki, 2001). When they find themselves in the integral

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[3] Properties of an architectural innovation are applied to product development and manufacturing.

phase, they must rethink the entire product, which involves accumulating integral knowledge about the new product. After an architectural innovation, established firms have difficulty understanding how components are linked together and interact with one another (Henderson & Clark, 1990). Thus, a firm that is searching for new architectural knowledge must change from looking for refinements in a stable product architecture to looking for new solutions within a constantly changing context.

Architectural innovation is one type of technological change. Technological change may happen in the form of incremental, modular, radical or architectural innovation (Henderson & Clark, 1990). Figure 4 summarizes the four types of innovation and categorizes the innovations along two dimensions. The horizontal dimension differentiates between how an innovation reinforces or overturns components. The vertical dimension differentiates between how an innovation changes or does not change the linkages between components. Incremental innovation is improvement in individual components where underlying core design concepts and the links between them remain the same. Thus, it reinforces the competitiveness of established firms, since it builds on existing core competencies. A modular innovation is one that only changes the core design concepts of a product. Moreover, a modular innovation associated with a new component is found to be easily managed through current market mechanisms (Prencipe, 2004). The well-defined interfaces enable the successful coordination and integration of the new component (Chesbrough & Teece, 1996). Furthermore, a radical innovation creates a new dominant design and a new sets of core design concepts. These new concepts are incorporated in new components that are coupled together within a new architecture. Radical innovation creates distinctive challenges for established firms since it destroys the utility of their existing resources and capabilities.

		Core Concepts	
		Reinforced	Overturned
Linkages between Core Concepts and Components	Unchanged	Incremental Innovation	Modular Innovation
	Changed	Architectural Innovation	Radical innovation

Figure 4: Four different types of innovation according to Henderson and Clark (1990).

2.6.2.1 *Implications of architectural innovation*

With regard to architectural innovation, much of what the firm knows remains important and useful, but some knowledge is no longer necessary for the new product architecture and may even interfere with the firm (Henderson & Clark, 1990). For this reason, firms are no longer able to coordinate the required exchange of information through communication channels that have been established with various suppliers and other actors. Indeed, even problem solving no longer requires a detailed analysis, conscious or exact execution. Therefore, architectural innovations are removed by information filters and communications channels that represent old architectural knowledge and incumbent firms require a substantial amount of time and other resources to identify a particular innovation as architectural. Once firms have realized that a particular innovation is architectural, they face a second source of problems and must subsequently switch to a new method of learning and invest in time and resources into learning about the new architecture.

Henderson and Clark have further provided examples of architectural innovations that imposed problems on established firms. They have also summarized the evolution of photolithographic alignment technology. The technology behind photolithographic alignment has changed four times based on architectural innovation and after each change, established firms failed commercially and lost market share. The first architectural innovation involved a shift from contact to proximity alignment, the second from proximity to scanning projection alignment and from scanners to first and second generation steppers. In each case, the core technologies of optical lithography remained, to a large extent, the same and a relatively large portion of the previous generation's technological knowledge could be transferred to the next. After each architectural innovation, however, the technology shifted to the integral phase in which companies holistically rethink how photolithographic alignment technology functions. However, in each case, the leader of the industry could not make the transition. Other examples of architectural innovation include: the implementation of a less modular architecture for bicycle drivetrains (Fixson & Park, 2008), the introduction of smaller copiers (Clark, 1987) and smaller transistor radios (Clark, 1987).

2.6.3 Organizational structures and knowledge management during the integral phase

After an architectural innovation, a company finds itself in the integral phase of technological development. This marks a time of uncertainty and ambiguity; Indeed, it is not clear how different technological elements interact with one another. Within the integral phase, technology is not yet well understood and an overall comprehension of how the parts of the product interact with one another is lacking.

2.6.3.1 Organizational structure

In order to strengthen a company's knowledge about the new product architecture, firms collaborate with various actors (suppliers, customers, research centers, universities, etc.) in various technological fields. Collaborating with a variety of actors helps the actors both strengthen the knowledge about a technology and advance the technology (Ozman, 2011). For example, International Business Machines Corporation's (IBM) leadership in the computer industry was exceedingly effective in the shift from 150 to 200mm wafers due to open collaboration practices (Chesbrough, 2005). Indeed, IBM developed a large open value chain that allowed them to collaborate with their equipment suppliers and other external sources. The collaboration structures in the integral phase involve various technological fields, but are characterized by weak and flexible organizational relationships (Granovetter, 1973). This allows companies to explore new technological areas using a broad search across a firm's boundaries. Companies should be open for creativity and closely follow technological developments that occur beyond their boundaries to explore novelties (March, 1991). Companies may have various ideas about a system's architecture and evolve these ideas through experiments and trial and error. In doing so, firms constantly improve their understanding about the product and start to understand the interdependencies of the various functional elements.

2.6.3.2 Knowledge management

After architectural innovation, firms must develop new architectural knowledge. Such knowledge is context specific and thus, difficult to articulate in documents. It is tacit and often an individual possesses it in the form of experience or know-how (Nonaka & Takeuchi, 1995). Companies have to gain new knowledge regarding how to manage technological interdependencies incorporated in modules within the new architecture (Chesbrough & Kusunoki, 2001). Firms must search for technological development beyond their firm's boundaries to explore novelties that help them adapt to the new product architecture (March, 1991). The integral phase requires the centralized management of coordination as well as that significant changes and adaptions be made to product components as well as that information be continuously exchanged and shared across the development teams, since architectural innovation changes the interfaces of the entire product (Chesbrough & Kusunoki, 2001). While much of what the firms know remains important and useful, some knowledge will no longer be required for the new product architecture and may even interfere with the firm (Henderson & Clark, 1990). Therefore, a number of the suppliers responsible for certain tasks in new product development processes remain relevant while others will no longer be required. Within the integral phase, firms are not able to coordinate the required exchange of information through communication channels that have been established with suppliers and other actors in the modular phase. Moreover, the interdependencies between the components are not well understood because they have changed. Within the integral phase, collaborating with different players strengthens the technological knowledge and progresses the technology (Ozman, 2011).

The following section examines the shift from the modular phase towards the integral phase. It explains how the shift towards the integral phase is triggered by organizational structures within the modular phase. This shift is illustrated by an arrow placed between the “organizational structure” box and the “product architecture” box during the integral phase. Moreover, it discusses how firms may be prepared for architectural innovation during the modular phase that changes the characteristics of the organizational structure and knowledge management.

2.7 How Technology Shifts from the Modular Phase

It has been observed that organization-based networks of manufacturers and suppliers emerge during the modular phase. Proactively involving key suppliers and possibly lower tier suppliers as well, early in the concept exploration and definition stages of product development projects, results in innovations within the system architecture and interfaces between components (Bozdogan et al., 1998). As soon as the modular product architecture has evolved, suppliers’ integration practices are enhanced industry wide within network-based development organizations, which triggers architectural innovation. The more intensive are the interactions between suppliers and manufacturers, the more opportunities there are for understanding the product and the better is the accumulation of architectural knowledge (Ozman, 2011). The tight cross-organizational relationships between manufactures and suppliers within network-based development organizations and the increase in opportunities for architectural learning increase the probability that an involved actor will innovate (Henke & Zhang, 2010), which in turn may lead to a new product architecture. Lee and Veloso (2008) studied the car industry between 1970 and 1998 and have found that architectural innovation emerges from supplier-manufacturer collaboration. Furthermore, Rosell and Lakemond (2001) reviewed 80 articles about suppliers' contributions to innovation in new product development and have argued that architectural innovation occurs when manufacturers and suppliers work together in new product development. Moreover, Sobrero and Roberts (2002) have suggested that innovation from suppliers increases when they are responsible for problem solving for highly critical components. They measured innovativeness with respect to the established knowledge base and referred to architectural innovation. Furthermore, they analyzed 50 supplier-manufacturer relationships for new product development within the European Major Home Appliance Industry. Henderson and Clark (1990) have explained that the transition from contact to proximity alignment in photolithographic was triggered by a supplier of contact aligners. The supplier introduced the first contact aligner that was equipped with proximity capability, but was not able to launch a well performing product. Moreover, they conceived the new aligner as a modified contact aligner since they understood it within the context of the established architecture. This transition is viewed as an architectural innovation because the core design concepts remained almost entirely untouched. The new aligner required a much more sophisticated understanding of the interrelationships between the components. They focused their attention on problem solving with regard to the old architecture rather than focusing on the new problems that were associated with the new architecture. In summary, collaborative and integrative organizational structures characterized by interfirm modularity during the modular phase of technological cycles may trigger architectural innovation, which in turn shifts the technology towards the integral phase again.

2.7.1 Increasing the network of collaboration beyond pure product development activities

Interestingly, manufacturers that integrate suppliers' knowledge of core component technology may trigger architectural innovation, shifting the technology towards a more integral phase and hence, decreasing the value of tight cross-organizational collaboration practices. Firms must adjust or completely change their standard operating procedures to design and develop a new product with a new architectural design. The possibility that architectural innovation may be triggered by tight cross-organizational relationships should force companies to rely upon, among other things, network-based product development organizations characterized by interfirm modularity. Additionally, they should interact with various old and new suppliers and customers as well as with research centers, universities, etc. to closely follow technological developments that occur beyond their firm's boundaries. This implies that during the modular phase, companies should have two types of organizational networks in place. The first network is characterized by the integration of knowledge of core component technology through the close incorporation of suppliers who are responsible for the development of such core components. In such collaboration practices, the interdependencies of components require coordination management at the knowledge and organizational levels and control for the corresponding relationships. Manufacturers outsource development work to suppliers within such networks, but remain knowledgeable in component technology that allows for conscious coordination and successful product integration. This type of network is efficient for managing incremental and modular innovation (Henderson & Clark, 1990), while the other type of network has similar organizational structures as the network explained within the integral phase. Furthermore, this network type is characterized by weak and flexible organizational relationships with various actors. Such a network structure involves technological fields that occur beyond the firm's boundaries and allows for an increase in new knowledge exchange between firms. New suppliers and various actors outside of a firm's environment should be considered for the second network. Having knowledge about related technological fields beyond a firm's boundaries increases the overall comprehension of the product and also enables firms to be prepared to change organizational development structures to adapt the focus of knowledge management and new product development practices as soon as the technology shifts towards the integral phase. Fujitsu, a disk drive producer, was able to adapt to the shift from the modular phase towards a more integral phase due to the knowledge the firm possessed about technology that was not incorporated into the established product architecture. Fujitsu outsourced the development of components to a network of suppliers. Simultaneously, they invested material and technology knowledge in areas that differed from their incorporated technologies. This knowledge helped them manage the new technology of magneto-resistive heads. Maintaining capabilities beyond the firm's boundaries allows firms to be better prepared to anticipate future interdependencies between system components, parts and interfaces. With the second type of network in place, firms are better prepared to switch to new methods of learning and to adapt to new architecture as soon as the system architecture begins to change (Henderson & Clark, 1990).

2.8 Discussion

The purpose of this study is to present a theoretical review of the literature on modularity relevant to the context of new product development literature. Modularity within this context originated from Simon's (1962) fundamental analysis of characteristics of complex systems and his illustration of design principles for such systems. Recent research has indicated that manufacturers who design modular architectures for technological products outsource development work for specific components while maintaining knowledge sharing and close cross-organizational relationships that allow for the successful management of coordination of suppliers' work and conscious system integration. As soon as a form of modular product architecture is established, network-based product development organizations emerge. Such networks are characterized by interfirm modularity. The product development organizations enhance supplier integration practices industry wide, which in turn may result in innovations within system architecture (Bozdogan et al., 1998; Brusoni et al., 2001; Henke & Zhang, 2010). As a consequence of the transformed product architecture, architectural knowledge embedded within companies and the corresponding problem solving processes become obsolete (Henderson & Clark, 1990). Moreover, the product development organization and ties between suppliers and manufacturers become obsolete to some extent, since manufacturers cannot rely upon suppliers' core competencies to develop and produce a new product with a new architecture. Firms no longer know component specifications and thus, are not able to adequately specify their component needs and requirements to outside suppliers. Manufactures may overcome these issues while having two types of organizational networks in place. One of these networks is characterized by the integration of suppliers' knowledge about core component technology for successful system integration and the other involves technological fields beyond the firm's boundaries. Firms with knowledge about technological fields outside the firm's boundaries enhance their knowledge about overall system architecture and are better prepared to anticipate future interdependencies between system components, parts and interfaces. Understanding forces that may lead to architectural innovation is important to understanding how companies may be aware of where an architectural innovation originates. Knowing the source of architectural innovation allows companies to better prepare for the subsequent integral phase that is characterized by accumulating knowledge about new interdependencies and interactions. When other aspects are not considered, this leads to a shift towards the integral phase, such as a radical innovation. However, in the case of radical innovation, the need to accumulate new knowledge about a new architecture is quickly apparent since a radical innovation changes the components of the products and subsequently, the new components interact in a new way that is immediately apparent (Henderson & Clark, 1990).

2.8.1 New value propositions

Current major industrial transitions (such as industry 4.0, Internet of Things, Digital Transformation or the transition of the energy sector) present challenging environments for established firms. Established firms that develop and produce modular products that involve a stable product architecture outsource development work to suppliers. Companies communicate through channels that reflect the architecture of a product, filtering out information that does not concern current architectural issues and thus, the involved problem solving strategies do not move beyond the architectural border. However, there is currently an increasing convergence of firms from previously distinct sectors (Brusoni, Jacobides & Prencipe, 2009; Jacobides & Winter, 2005). Technology does not progress and develop within a sector, but rather shapes (and is shaped by) industries from distinct sectors. Industries are no longer easily defined. Firms that only compete within organizational networks characterized by interfirm modularity should adapt to practices that involve collaboration actors from distinct fields.

Without considering such distinct actors, companies may miss technological and organizational diversity that can afford them future strategic flexibility. Looking beyond architectural boundaries allows firms to introduce changes to the established way of doing things that may ultimately lead to innovations. Organizations that primarily focus on networks characterized by interfirm modularity may not leverage enough distinction in terms of specializing and business model innovation (Brusoni et al., 2009). For example, the traditional value proposition of an LED lamp installed in a house is to provide light. However, an LED lamp and digital possibilities such as light sensors, radar sensors, connectivity and cloud analytics allow for new value propositions. New value propositions are real-time simulations of presence, mobile alert or other digital services (Fleisch, 2016). In this case, the internet of things combines physical things with digital features to offer new value propositions and business model patterns. A company that only has experience developing and producing LED lamps, but wants to adapt their business model while offering a new value proposition must look beyond their boundaries. The firm needs to build component knowledge in sensors, connectivity devices and data analytics. Accordingly, firms examine various other firms and interact and collaborate with firms from distinct industries to be prepared for future challenges that may completely change the product architecture and subsequently, the way in which the firm conducts business.

2.9 Future Research

Many scholars have discussed modularity and its implications at the organizational and knowledge levels during the modular phase. I, however, attempt to exhibit a more nuanced theoretical framework while developing a model that relates implications of modularity at the organizational and knowledge levels across a technological cycle. Empirical future research should adopt a holistic approach and thus, focus on how organizational structures and knowledge management trigger the shift from the modular phase to the integral phase. Future researchers may explore whether tight cross-organizational integration triggers architectural innovation and whether a second, loosely coupled network that looks beyond a firm’s boundaries may help overcome the issues of architectural innovation (Henderson & Clark, 1990). Moreover, it would be interesting to analyze to what extent other development departments, such as marketing or finance, may be affected by architectural innovation. For example, how architectural innovation affects other departments or how other departments affect architectural innovation through tight collaboration practices and knowledge sharing practices with suppliers or other actors.

Lee (2007) has examined the impact of alliances and networks on processes of industry convergence. By tracking how such alliances and networks of organizations from distinct industries trigger architectural innovation, scholars may illuminate processes of industry convergence.

Important criteria to consider when initiating supplier collaboration include: supplier capability, technological uncertainty, modularity, geographical proximity and trust (Rosell & Lakemond, 2011). Another promising path for future research is to examine which of these criteria are related to innovation capacity from suppliers that ultimately shift the technology towards the integral phase.

Chapter 3 Product Modularity and Innovative Capacity: A Quantitative Study among Medical Technologies Companies in Europe

3.1 Introduction

Being innovative is the source of a firm's productivity growth and it also stimulates and facilitates organizational change (Drucker, 2001). Innovation leaders across 25 sectors of the economy regularly outperform the average share price index on various stock markets (Innovar, 2008). Moreover, they achieve stronger growth, control a relatively large portion of the market and achieve better profitability (Tidd & Bessant, 2002). The present study investigates innovation by examining the processes and structures by which firms develop new products (Brown & Eisenhardt, 1995). Kleinschmidt and Cooper (1991) have argued that new products create opportunities for differentiating existing products and providing technological product advantages. New product introductions not only provide a number of advantages, but also is associated with an increase in long-term financial performance and firm value. (Brown & Eisenhardt, 1995; Kang & Montoya, 2014; Powell & Brantley, 1992; Schilling & Hill, 1998). In this chapter, the unit of analysis is a product development project within the medical technology and device industry. Furthermore, modularity as a design principle for developing new products is the main concept that makes it possible to build innovative and high-performing products (Baldwin & Clark, 1997; Boer, 2014; Cusumano & Nobeoka, 1998).

In modular products, the components or sets of components can easily be mixed and matched within the rules of the product architecture, which defines the arrangement of functional elements to physical components and specifies the interaction between the components (Ulrich, 1995). Interactions between two components work through an interface. Sanchez and Mahoney (1996) have indicated that the specification of interfaces permits a range of functional or physical variations within any given component without requiring that changes be made to the overall product design or the design of the other components. Standardized interfaces enable different combinations of components to be mixed and matched, which in turn results in different products with distinctive bundles of component-based functionalities, features and performance levels (Sanderson & Uzumeri, 1995). As a consequence of a relatively high degree of modularity, a company has much more flexibility with regard to configuring the end products (Sanchez, 1995; M. Schilling, 2000).

However, there are cases when a relatively modular product architecture is disadvantageous. Indeed, simply developing modular products does not solve all the problems in technological innovation. For example, modularity does not achieve better product performance in terms of changing user needs (Fixson & Park, 2008), create high performing products in terms of acceleration or speed (Ulrich, 1995) or decrease product volume (Celona et al., 2007). Nevertheless, many companies appear to apply the notion of modularity to such an extent and consequently, decrease the chance for breakthrough innovations (Fleming & Sorenson, 2001).

3.1.1 Innovativeness of modular designs

Thus, it is necessary to consider that although a product architecture is relatively modular, hidden interdependencies may remain. Components with standardized interfaces require the manufacturers of these components to coordinate and control for relationships between the components (Staudenmayer et al., 2005). Staudenmayer and her colleagues have argued that rather than eliminating the interdependencies within modular product development, firms should manage the interdependencies between components. However, unpredictable changes from other firms may change the interdependencies between components and thus, change the overall architecture of the product (von Hippel, 1998). Isolated management of modular architecture can hinder such designs from incorporating some form of strategic flexibility (Fleming & Sorenson, 2001). As a result, a modular system may fail to foster learning and innovation. Thus, firms must be aware of these properties, i.e. that modular products still require that interrelations between components be managed, whereas new interdependencies to distinct technology may change components and interrelations between them (Henderson & Clark, 1990).

Currently, firms from previously distinct sectors converge (Brusoni et al., 2009) and definitions of industries change along with competitor and capability profiles (Jacobides & Winter, 2005). As such, scholars have highlighted the important aspect of technology in industry convergence that crosses industry borders and both shapes and is shaped by various industries. Technologies are crossing over to various industries, making it difficult for companies trying to improve their products based on modularity principles to launch innovative products with distinct technologies. For example, introducing digital possibilities into traditional products involves looking beyond a firm's boundaries (Fleisch, 2016). Research has revealed that a firm that develops products with a relatively high degree of modularity may launch highly similar products with limited differentiation in new products (Robertson & Ulrich, 1998). Thus, instead of trying to improve the overall product, designers are likely to focus on improving components and may overlook improvements that can be made to the overall product, which may come from outside the industry (Henderson & Clark, 1990). Quoting Fleming and Sorenson's (2001) *The Dangers of Modularity*, "The process of innovation is, virtually by definition, filled with uncertainty; it is a journey of exploration into a strange land." They have found that while using interdependent components often results in more complicated and uncertain innovation, ultimately it results in breakthrough products.

The setting of industry convergence requires a comprehensive examination of modularity and its implications for aspects of innovativeness. Thus, I include the concept of innovativeness within my analysis. This concept measures the extent to which a product is sold within a distinct market and the extent to which the product incorporates new technology. As a result, I am able to explain how modularity relates to changing market and technology borders. Another important discussion related to modularity is supplier involvement. It is widely accepted that supplier involvement is an inherent dimension of developing modular products. Manufacturers who develop relatively modular products outsource the development work of components to suppliers (Brusoni & Prencipe, 2001; Campagnolo & Camuffo, 2010; Furlan et al., 2013). Thus, researchers have argued that modularity helps manufacturing firms outsource efficiently and effectively, thus facilitating the integration of suppliers in new product development (Baldwin & Clark, 1997, 2000; Brusoni & Prencipe, 2001; Furlan et al., 2013; Garud, Kumaraswamy & Langlois, 2002). Such a collaboration setting is characterized by the term interfirm – meaning that the development and production work of various components is distributed across different firms (Baldwin & Clark, 2000; M. Schilling, 2000). Therefore, I include supplier involvement as a concept. The final concept I include is new product performance in financial terms. Insight into the financial performance of products makes it possible to relate the concepts of modularity, innovativeness and supplier involvement to the financial success of a product on the market.

3.1.2 Research gap

First, it is known that modularity makes it easier for designers to innovate at the component level, which increases the probability that incremental and component innovations will be created as well (Garud & Kumaraswamy, 1995; Sanchez, 1995). However, designing modular products does not lead to breakthrough innovation, since new products based on modularity may result in limited differentiations (Robertson & Ulrich, 1998). Second, modularity may be associated with an increase in new product performance in terms of financial profit (Jacobs, Vickery & Droge, 2007; Kang & Montoya, 2014; Worren et al., 2002). For example, modularity is associated with a decreases in costs and cycle times and with an increase in flexibility (Jacobs, Vickery & Droge, 2007). Third, modularity facilitates supplier integration practices in new product development. For example, Howard and Squire (2007) have suggested that manufacturers of modular products involve suppliers in new product development. Thus, suppliers are valuable for new product development for products in which various technologies are captured (Sako, 2002). However, there is a limited understanding of how the concepts of innovativeness, new product performance and supplier involvement are related to one another and subsequently, how they relate to modularity. Such an approach helps develop a more comprehensive understanding of modularity in new product development than has previously been developed. Indeed, scholars have emphasized the point that implications of modularity in new product development need to be analyzed in a more holistic manner (Furlan et al., 2013; J.H. Mikkola, 2006; Stanko et al., 2015). For example, studies should explore whether or not modularity is positively related to product innovativeness and if it simultaneously is associated with an increase in new product performance that is due more to increasing flexibility and decreasing cost within the frame of an established product architecture (Worren, Moore & Cardona, 2002). An established architecture is characterized by a dominant design that marks a point in time when a general agreement about attributes of the product's performance and the actual product's architecture was established (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Clark, 1985). On the one hand, modularity facilitates supplier involvement in new product development (Furlan et al., 2013), which is associated with an increase in the innovativeness of products (Sun et al., 2010). On the other hand, however, innovating on the basis of an established product architecture only leads to products with limited differentiations (Robertson & Ulrich, 1998). Since these contrary findings require additional research, this essay develops a better understanding of the dynamics between the concepts of modularity, supplier involvement and the innovativeness of new products

3.2 Theoretical Framework

The theoretical framework below outlines the more comprehensive approach used within the present research and illustrates the hypotheses of this study.

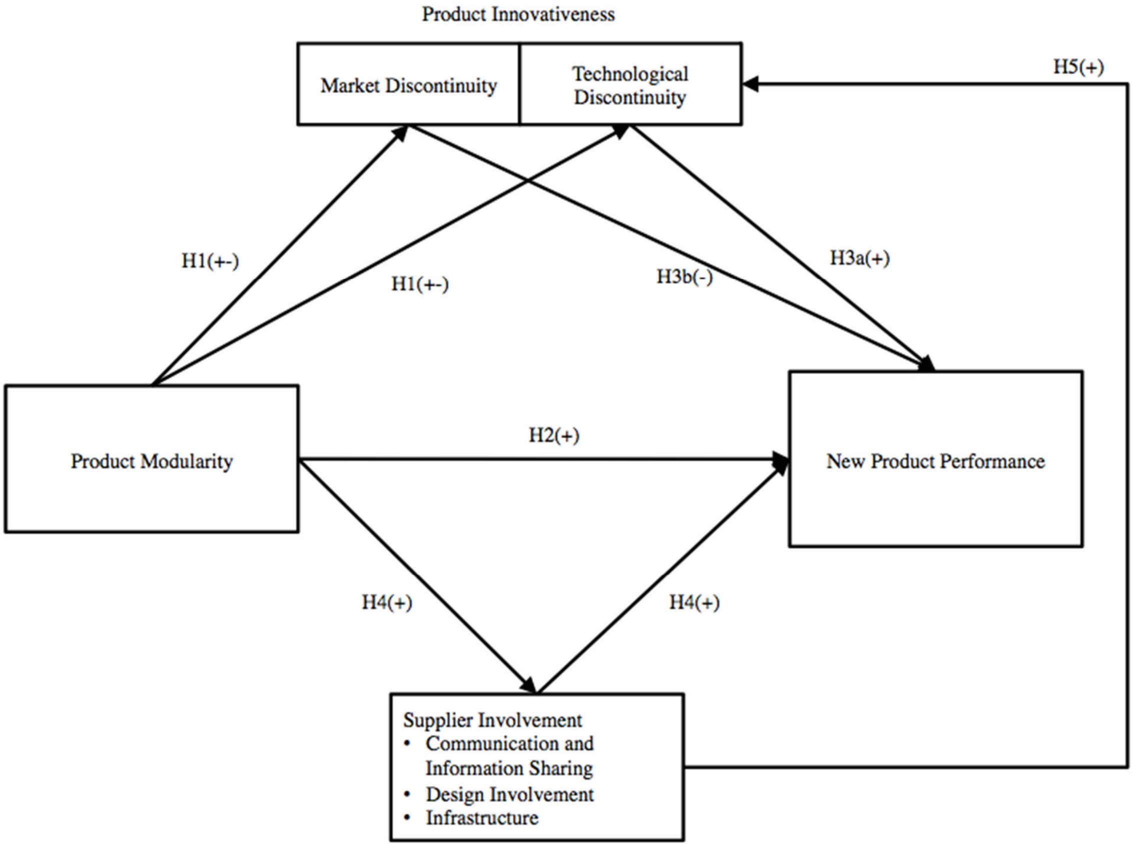

Figure 5: The hypothesized conceptual model of the relationship between modularity, innovativeness, supplier involvement and new product performance in financial terms. The letters refer to the hypotheses.

The article defines product innovativeness from the firm perspective. Danneels and Kleinschmidt (2001) and Garcia and Calantone (2002) have discussed the firm perspective and whether the technology or the market is new to the firm. Consequently, they split the firm perspective into two separate dimensions of technological newness and market newness. Technological newness explores the extent to which a product can be manufactured at an existing company plant and with existing equipment, i.e. to what extent the technology used for the development of a product is familiar to a company. Market newness, on the other hand, examines the newness of the product category, i.e. to what extent the new product competes with products from existing competitors[4]. In summary, the

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[4] Danneels and Kleinschmidt (2001) have also summarized the customer perspective and suggest that it examines innovation attributes (e.g. the product's ability to provide benefits or features not offered by alternative products), adoption risks (risks regarding uncertainty, performance, social loss or harm to user) and levels of change necessary for adoption (changed in established customer behavior patterns).

firm perspective is defined as the potential discontinuity a product may imply within a firm's technological processes and marketing processes in new product development practices (McNally, Akdeniz & Calantone, 2011). The term innovativeness may further be understood as a measurement of how successful a product is on the market. While I do not include the success variable within the concept of product innovativeness, I have defined a separate variable "new product performance" that captures the aspect of market success. This is explained further for hypothesis two.

3.2.1 Knowledge creation theory

Knowledge is explained in three dimensions (Nonaka, Von Krogh & Voelpel, 2006). First, knowledge is a true belief, meaning that individuals justify the truthfulness of their beliefs based on observations of the world. Arguments are built on unique viewpoints, personal impressions and experience (Nonaka & Takeuchi, 1995). Second, knowledge is an individual's ability to understand a certain setting or situation and act accordingly (Von Krogh, Ichijo & Nonaka, 2000). In this case, knowledge is more about acting on a situation rather than solving pre-arranged problems. Third, knowledge is explicit and tacit (Nonaka, 1991). Knowledge then, can be articulated, formulated or captured in drawings (or products) and is explicit. Moreover, knowledge related to senses, movement skills, physical experience, intuition or implicit rules of thumbs is tacit (Polanyi, 1966). In companies, knowledge is created through a four-stage process that involves socialization, externalization, combination and internalization (Nonaka & Takeuchi, 1995). Socializing concerns sharing tacit knowledge across and among actors. Externalization refers to the aim of articulating tacit knowledge as explicit concepts. The purpose of combination is to combine different entities of explicit knowledge and internalization aims at embodying explicit knowledge as tacit knowledge.

Henderson and Clark (1990) have defined four types of innovation. Modularity deals with incremental (improvements to individual components) and modular innovations (replacing an existing component). However, they have described two additional types of innovation: radical innovation and architectural innovation. Radical innovation establishes an entirely new technology in a new product design and architectural innovation changes the way in which existing components interact with one another. The next section discusses the implications of modularity along the four types of innovation and relates these implications to the knowledge creation theory.

3.2.2 Incremental and modular innovation

By mixing and matching different combinations of modular components, a company can create different products with unique bundles of component-based functionalities and performance levels (Sanderson & Uzumeri, 1995). This implies that brining new products to the market is rather simple for companies that apply the modular design strategy. A simply adapted module with additional or improved functionality can be combined with existing ones, resulting in new products within the product portfolio. Providing that the specification of the interface does not change, the engineers can experiment o and modify the design strategies of a module without requiring changes to other modules – they do not need to understand the entire system (Garud & Kumaraswamy, 1995; Ulrich, 1995). Therefore, it is simple for designers to innovate on the component level, which is associated with an increase in the likelihood of creating incremental and radical component innovations (Garud & Kumaraswamy, 1995; Sanchez, 1995). Pil and Cohen (2006) have argued that modular design accelerates incremental innovations through simplifying the scope of the solution area, maintaining constant boundaries of the solution area and disconnecting the solution area from other elements. The aforementioned positive implications of modularity on innovativeness mainly refer to innovations within an established product architecture. When incrementally or modularly innovating their products, companies only combine existing knowledge and internationalize the knowledge across the development team. According to the knowledge creation theory, their ability to create new knowledge is limited. Such companies have reached a state of internationalization in which many actors of a manufacturer have tacit knowledge about the product. Thus, components of products incorporate tacit knowledge in explicit forms that can be formulated and articulated. Standard interfaces are also a form of explicit knowledge.

3.2.3 Architectural and radical innovation

Innovative components can be combined with current components, which leads to combinatorial innovations[5] and higher innovativeness of the entire product (Clancy, 2015; Lau, Yam & Tang, 2011; Varian, 2003). However, combinatorial innovations relate to rearranging components in a new way that is characterized by architectural innovation (Henderson & Clark, 1990). Successful architectural innovation requires firms to accumulate new integral knowledge of the new product architecture. Such knowledge is, by definition, context specific and difficult to articulate (Nonaka & Takeuchi, 1995). Furthermore, architectural innovation involves building new architectural knowledge within a context in which some of the previous architectural knowledge may be relevant. After architectural innovation, firms must learn from and accumulate holistic and integral knowledge about new interdependencies and interactions between the components within the overall product. Radical innovation changes the entire product design and concerns new technology that has not yet been explicitly captured within explicit components. Understanding a new product architecture or a new technology involves accumulating integral or holistic knowledge on the new product. Such a setting is characterized by the

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[5] A combinatorial innovation occurs when innovators combine or recombine different component parts to create new inventions. The launch of a set of new modules, for example, requires developers to conduct many trial-and-error processes. This may lead to many creative products being built with the new modules. A famous example of this can be observed in the development of the gasoline engine that led to a wave of combinatorial innovations. The new engine was incorporated into many different devices like motorcycles, cars and aircrafts.

integral phase in technological development according to Chesbrough and Kusunoki (2001). How the new or adapted components interact with one another is not clear during the integral phase. During this phase, furthermore, technology is not yet understood well and overall knowledge of how the parts of the product interact with one another is lacking and must be accumulated. Such knowledge is tacit knowledge and is usually embedded in an individual's experience as knowledge (Nonaka & Takeuchi, 1995). Tacit knowledge involves sharing such knowledge across and among actors, referring to those involved (people or organizations) from distinct fields that may be related to a field that is not directly connected to the established product architecture. Radical innovation and architectural innovation relate to the starting point of the knowledge creation process. For such innovations, firms need to share their tacit knowledge about the new architecture or the new technology with various involved actors. The companies in this stage have not yet reached externalization, in which tacit knowledge is incorporated within explicit concepts or components. For managing radical and architectural innovation, companies must rethink their architecture and build entirely new knowledge about a new product design or technology (Henderson & Clark, 1990).

Lau et al. (2011) have summarized the disadvantageous implications of modularity on innovativeness. First, designers need to understand a product architecture before they can modularize a system (M. Schilling, 2000; Ulrich, 1995). This may be associated with a decrease in product innovativeness because developers must follow past experience, past international standards and past compatible interfaces to define the modular product architecture. Second, a high degree of modularity may also hinder innovation because of a high product similarity and limited differentiation in new products (Robertson & Ulrich, 1998). Third, Ethiraj and Levinthal (2004) have argued that different designers may only have specific knowledge of certain highly modularized components, thus making it more difficult for them to cooperate and share knowledge; This results in poor overall product innovation. Designers may overly focus on optimizing the components and consequently, not be aware of overall product innovation in terms of radical or architectural innovation.

3.2.4 Hypotheses building

While modularity appears promising for modular and incremental innovation, it may hinder companies from managing radical and architectural innovation.

To consider both perspectives, this study proposes an inverted u-shape relationship between modularity and innovativeness. This implies a positive relationship in the beginning when the degree of modularity is increasing. However, after a certain degree of modularity, the impact on innovativeness is negative – further increasing the degree of modularity is associated with a decrease in product innovativeness.

H1: Modularity has an inverted, u-shaped relationship with product innovativeness.

Loosely coupled components that may be mixed and matched allow a company much more flexibility in configuring the end products (Sanchez, 1995; M. Schilling, 2000). Theoretically, with each additional component it is possible to add a new product to the product catalogue. Cusumano and Nobeoka (1998), Kang and Montoya (2014), Pauwels et al. (2003) and Worren et al. (2002) have found a positive, direct relationship between a large product portfolio and a firm's financial performance. Consequently, developing modular products may lead to better financial performance measures. Other studies have also proposed a positive relationship between modularity and a firm's performance. Jacobs, Vickery and Droge (2007) have found that modularity leads to lower costs, higher flexibility and smaller cycle times. Many companies that pursue a modular product design strategy increase product variety with innovative products that additionally is associated with a decrease in development and production costs (Cusumano & Nobeoka, 1998; Sohail & Al-Shuridah, 2015). Moreover, Pil and Cohen (2006) have argued that firms that develop modular products are able to create new products faster than their competitors and thus, may create more marketable products. Other studies have further supported the time benefits of modularity (Gershenson, Prasad & Zhang, 2004; Sanchez & Mahoney, 1996; K. Ulrich, 1995). The time performance measurement is important since time issues are indirect cost issues. McNally, Akdeniz and Calantone (2011) examined 444 different new product development projects of seven US firms from various industries and have argued that the less time a firm needs to develop and launch a new product, the more profitable is the firm. Analyzing 201 manufacturing plants, Danese and Filippini (2010, 2013) have found a positive, direct relationship between modularity and on-time product launch and product performance in terms of product capability, performance and innovativeness.

According to the suggestions above, I formulate the next hypothesis as follows:

H2: Modularity has a positive relationship with new product performance.

The next two hypotheses relate the concept of product innovativeness to new product performance.

Katz (2000) and Tidd, Bessant and Pavitt (2001) have argued that product innovativeness is positively related to new product performance: Innovative products that offer incremental improvements provide companies with a constant cash flow. Kleinschmidt and Cooper (1991) have argued that product innovativeness has a positive impact on new product performance. Indeed, both less innovative products (i.e. product modifications, revisions, cost reductions or repositionings) and highly innovative products are financially successful. However, from modularity research it can be observed that at some point, the product must be newly defined from scratch with an entirely new product architecture to remain successful (Henderson & Clark, 1990). Indeed, radical innovation is more profitable than, for example, incremental innovation (Sheremata, 2004). Additional research has indicated that perceived product innovativeness is positively related to new product performance (Henard & Szymanski, 2001). Innovativeness is measured in terms of perceived newness, originality, uniqueness and radicalness. However, the construct of technological discontinuity is measured as the extent to which a product can be produced within the existing company plant and using pre-existing equipment or to what extent the technology used for the development of a product is familiar to a company or not. From capabilities and resource research, it can be gleaned that companies perform better when they can build upon existing capabilities and resources (A. Simon, 2012). Such research has its roots in Penrose (1959) and Barney (1991) and has emphasized the importance of a firm’s resources and capabilities in strategically guiding the firm. Both resources and capability portfolios are of major concern for strategy building. Nevertheless, I define the following hypothesis as follows, but concede that there are arguments against this hypothesis.

H3a: Technological discontinuity has a positive relationship with new product performance.

The inverted u-shape relationship between modularity and innovativeness implies that a mediating factor will not exist for relatively high levels of modularity because high levels of modularity are associated with a decrease in product innovativeness.

Possessing a substantial amount of marketing knowledge and proficiency, along with marketing synergy, is an important contributor to a new product’s success (Cooper, 1979). Indeed, possessing market knowledge has been referred to as market familiarity and is important since it helps managers understand how to communicate effectively with customers. Research has indicated that product success is more likely in familiar markets (Souder & Song, 1997). When familiarity is low, as in the case of marketing discontinuities, new product success is more difficult to achieve. However, market success is also related to capabilities and resources, as previously noted. Capabilities and resources are an important contributor to market success (Simon, 2012). In a case in which companies launch a new product in a new market, it may be that they possess capabilities and resources that are important to serve the new market. The following hypothesis may only be true in markets where capabilities and resources do not play an important role for financial success and thus, may not be true in cases where firms enter a new market with existing capabilities and resources.

H3b: Market discontinuity has a negative relationship with new product performance.

These paragraphs describe the mediating role of supplier involvement in the relationship between modularity and new product performance. Existing research has argued that product functionality may be matched with the corresponding technical skills of a collaborator in the development team (Chesbrough, 2005). In a modular product, a component has integrated functionalities and is coupled to the overall product through a standardized interface. Standardized interfaces allow a manufacturer to outsource the development and production of certain components. The required component knowledge reflects the scope and depth of the supplier’s core competencies, from which the manufacturer profits, while outsourcing the development activities to such suppliers (Cabigiosu et al., 2012; Campagnolo & Camuffo, 2010; R. N. Langlois & Robertson, 1995).

However, outsourcing development activities to a key supplier also implies that the manufacturer may still involve key suppliers in the overall product design and engineering. Howard and Squire (2007), while analyzing a sample of 104 UK firms across eight industry sectors, have suggested that modularity is positively related to supplier involvement in new product development if the manufacturers and suppliers develop the product together. Jacobs et al. (2007) have further revealed that integrating external parties in the design process fully mediates the effect of modularity on cost and flexibility performance; Firms need to cooperate with outsourcing partners to ensure having complementary resources, skills and knowledge. These complementary capabilities are crucial to ensuring that the components fit perfectly with the overall product (Hsuan Mikkola, 2000). Cabigiosu et al. (2012) have agreed that in order to take advantage of the benefits of modularity, companies must invest in component-specific knowledge. Furthermore, they have concluded that modularity requires an investment in components technology to remain within the components knowledge domain in order to take advantage of modularity. Brusoni et al. (2001), Brusoni and Prencipe (2001), Furlan et al. (2013) and Takeishi (2002) have found that manufacturers with increasing component knowledge can evaluate and integrate components more effectively than firms with little component knowledge. The range of new technologies captured in a car, for example, has increased over time (Biosca O., Ulied A., Caramanico G., Bielefeldt C., Calvet M., Carreras B., Rodrigo R., Cooper J., Fonzone A., Stewart K., Condie H., Schnell O., Mandel B., Bak M., Borkowski P., Pawlowska B., Matthews B., Chen H., Shibayama T., Lemmerer H. & Emberger G., 2013). Thus, manufacturers should involve suppliers in different stages of product development projects, share information and demonstrate openness to increase the supplier's innovation activities that potentially benefit the manufacturer (Henke & Zhang, 2010). Overall, a positive interaction effect between modularity and supplier involvement on new product performance exists when high levels of modularity accompany high levels of supplier involvement (Danese & Filippini, 2013). Accordingly, I define the next hypothesis:

H4: Supplier involvement positively mediates the relationship between modularity and new product performance.

The remaining relationship exists between supplier involvement and product innovativeness. The suppliers provide the customers with new ideas, such as how to integrate new materials or new machinery into the production process, while manufacturers actively search for new technologies or ideas outside the firm's boundaries and work with suppliers to create customer value (Chesbrough, 2005). Consequently, the manufacturer may increase its own knowledge base through the integration of suppliers. Possessing a better overall product knowledge and understanding the interdependencies of a system allows for faster innovations through experimentation (Brusoni et al., 2001). Moreover, Sun et al. (2010) have suggested that supplier involvement in new product development is positively correlated with product innovativeness. The more a supplier becomes involved and knows about the manufacturer's needs, plans, development strategies and programs, the more suppliers realizes that they can secure future business opportunities with the customer through their innovation-related activities. Thus, the supplier is more committed to innovation activities and consequently, both the supplier and the customer benefit from these activities (Henke & Zhang, 2010). According to the above literature, I define hypothesis 5 as follows:

H5: Supplier involvement has a positive relationship with product innovativeness

3.3 Research Methodology

3.3.1 Instrument

In general, I followed the guidelines described by Dillman et al. (2008) with regard to administering the survey. I developed Likert-type measurement scales for the concepts described in previous sections. Moreover, I reused or adapted questions for the scales that have already been used within the literature. Table 2 displays the questions in a shortened form. Four items measure the degree of modularity. I developed these items based on existing scales of modularity (Ahmad, Schroeder & Mallick, 2010; Duray, 2004; Worren et al., 2002). This study measured new product performance in terms of accomplishment of sales and profit goals as well as the product's profitability. In accordance with the conceptual frameworks suggested by Booz, Allen and Hamilton (1982), Danneels and Kleinschmidt (2001), Garcia and Calantone (2002) and McNally et al. (2011), I operationalized product innovativeness into two factors. One of these factors consists of items that measure the potential discontinuity a new product may create within the firm's technological processes and the other consists of items that measure the potential discontinuity a new product may create within the firm's marketing processes. To capture supplier involvement practices, I included the three factors "communication and information sharing," "design involvement" and "using common infrastructure with key suppliers" (Jayaram, 2008). These three factors each consist of several items.

However, I could not use all of the scales in their entirety because I wanted the questionnaire to be relatively short to increase the response rate (Dillman et al., 2008). Thus, I excluded a number of questions from existing scales that measure the concepts of product innovativeness (Danneels & Kleinschmidt, 2001) and new product performance (Worren et al., 2002). However, I developed other new scales to maintain industry-related controls. The development of these scales was supported by discussions with doctoral researchers, managers and executives from a consulting company within the relevant industry, managers from manufacturing companies and managers from two leading industry clusters. Furthermore, the interviews helped to refine the definitions of the concepts and identify the appropriate wording that should be used within this particular industry. Additionally, the managers and executives from the consulting company and the doctoral researchers and managers from the industry clusters provided feedback on the first version of the questionnaire.

Since the medical technology and device industry is exceedingly diverse, the study controlled for possible intra-industrial effects within the analysis by using dummy variables for the product categories[6]. Collecting data about the industry indicated that regulatory rules have become more rigorous over the last couple of years. Therefore, I developed one scale to measure the extent to which the

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[6] These categories include the following: electromechanical products, inactive implants, laboratory equipment, hospital hardware, etc.

regulatory rules[7] were new to the firm and one item to measure the risk classification[8] of the product as control variables. Furthermore, the fieldwork indicated that the question concerning whether or not a product will be reimbursed by insurance companies has implications on the go/no go decision for a new product development project. Consequently, I included a question about reimbursement as a control variable[9]

I measured the constructs at the product level. For instance, the modularity construct measures the specific modularity of one product. This allocation allowed me to be more detailed in my research. Consequently, those who answered my questions could not aggregate their answers on the firm level.

3.3.2 Sample

The medical technology and device industry is interesting for such a study since there might be a slight variance between firms regarding the degree of modularity due to the presence of distinct product categories within this industry. This heterogeneity suggests that research results may be more globally applicable than is typically the case for a single case study. This industry is also known to use advanced technologies and by its strategic importance, to invest in innovative solutions (Department of Commerce, 2009; Dümmler & Willhalm, 2008; Hofrichter & Dümmler, 2014; Medical Cluster, 2015; TÜV SÜD, 2016). Moreover, the industry is characterized by a relatively high level of research and development expenditures, which suggests an innovative climate (Buchs & Mazur-Hofsäss, 2011; Hofrichter & Dümmler, 2014; Medical Cluster, 2014). Successful supplier involvement in new medical device development is important and additionally, suppliers are often a source of innovation for the manufacturers (Interview, 2015; Pullen, De Weerd-Nederhof, Groen & Fisscher, 2012). Indeed, first tier suppliers often offer entire systems and utilize service providers and outsourcing partners (Medical Cluster, 2014). Given that medical technology products typically only last 18 to 24 months before a modified product is launched (Medtech Europe, 2013), examining modularity within this industry appears to be reasonable. Indeed, within this industry companies develop modular products to constantly launch new products.

I identified firms from contact lists provided by a leading consulting firm and three industry associations (Dachverband Schweizer Medizintechnik-FASMED, Bioalps and Medical Cluster). I checked every firm on the list to confirm that it is a manufacturer within the observed industry. First, I sent out a pre-notice letter informing the possible respondents that they would receive an invitation

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[7] A Likert-type scale was used to obtain information regarding to what extent the applied regulatory procedure was familiar to the firm.

[8] Classifications: Class I, Class II A, Class II B and Class II products - according to the EU Medical Device Directive.

[9] Yes if the application gets reimburse and no if not.

to conduct an online survey. The pre-notice letter asked whether the potential respondents possessed knowledge about recent product development projects, including performance information. If they did not match the criteria, they could nominate another employee within their company with the appropriate experience and knowledge. Not many respondents nominated someone else. Finally, I sent out the email with a hyperlink to the online survey to the remaining 450 contacts on the list (318 in Switzerland, 101 in Germany, 4 in Liechtenstein, 9 in Austria and 18 in the UK). Follow-up emails were sent out to managers. Apart from the 18 UK companies, firms were based in the German-speaking area of Europe (DACH). Studying the medical technology sector primarily within the DACH area seems appropriate given its importance within this field: Medical technology's share of all patent applications is almost three times as large in Switzerland as the global average and Germany has the highest absolute number of individuals employed within the medical technology and device sector, while the number of employees per capita is highest in Switzerland. This indicates that this particular sector is important within both countries. Moreover, the number of companies and employees within the industry in Austria exhibit relatively high growth rates, indicating the growing importance of this industry in Austria (Federal Ministry of Science Research and Economy, 2015).

Of the 450 invitations emailed, 132 responded for a response rate of 29%. However, 32 respondents did not qualify since they do not develop and produce any products. Since I asked respondents to optionally choose two product development projects, I gathered data about 175 new product development projects. For the first project, respondents could choose any project that had recently been completed and for the second project, they were asked to choose a more successful or less successful one compared to the first project. Finally, 143 projects were used since I applied a listwise deletion for 32 observations due to missing data.

3.4 Results

3.4.1 Construct reliability and validity

Table 2 displays the Cronbach alpha of the four constructs used within the model. A Cronbach alpha measures the extent to which the variables of a construct are positively related to one another. The alphas range from 0.62 for modularity to 0.88 for new product performance. However, while one alpha is less than 0.70, which is often used as a cut-off point (Nunnally, 1978), I still included this variable since methodological researchers have demonstrated that the routing and strict use of a 0.70 cut-off is not appropriate when no other types of reference are taken into account (Cortina, 1993; Schmitt, 1996)[10] .Schmitt (1996) has further argued that even relatively low alphas – around 0.50 – are acceptable if the measures have other desirable characteristics, such as meaningful content coverage or reasonable unidimensionality. I ascertained that the measures have satisfactory unidimensionality by performing a factor analysis, meaning that the items belonging to the variable modularity load on that factor. Thus, the content of the variable is meaningful since it has previously been used in other studies.

I followed the usual procedure for the confirmatory factor analysis (CFA) to check the convergent validity and discriminant validity of the factor structures. The maximum likelihood estimation and standardized factor loadings were used. In general, the results support the three factor model developed by Jayaram (2008) that captures supplier involvement. However, I had to delete a number of items that measure supplier involvement due to cross loadings. Moreover, one standard factor loading of the item “common linked information systems (IT)” is 0.37 and thus, below the threshold value of 0.4[11] (see Table 2.) However, I decided to retain the item since it is fundamental in guaranteeing the content validity of the factor “using common infrastructure with key suppliers” within the construct supplier involvement and since the factor loading is numerically near 0.4.

The construct validation included tests for content, convergent and discriminant validity. Content validity is typically assessed by expert judgment through an extended literature review. Thus, it is not likely that this study has problems with content validity because the survey instruments were mainly adopted from the extant literature and confirmed by several reviews.

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[10] There is a mathematical reasoning for why relatively low alphas should still be taken into account. Relatively large differences in alphas have relatively small effects on validity: with an alpha of 0.70 the upper limit is 0.84, whereas with an alpha of 0.49 the upper limit is still as high as 0.70.

[11] Stevens (1992) has suggested using 0.4 as a cut-off criteria, irrespective of sample size.

Table 2: Factor analysis outcome. Supplier involvement consists of three and product innovativeness of two factors.

Variable name and items	**Factor loading**
Modularity (α=0.62)	
Product can be decomposed into separate modules	0.52
Changes in key components without redesigning others	0.70
Product has a high degree of component carry-over	0.50
Product components can be reused in various products	0.49
New product performance (α=0.88)**	
Product has achieved our sales goal	0.87
Product has achieved our profit goal	0.93
Product has had great profitability	0.77
Supplier involvement (α=0.87)	
Participation of key suppliers in development team	0.74
Direct communication with key suppliers	0.71
Sharing design knowledge with key suppliers	0.88
Colocation of project personnel and key suppliers	0.47
Common linked information systems (IT)	0.37
Shared education and training programs with key suppliers	0.52
Involvement for prototype development	0.61
Involvement for defining the architecture of new products	0.58
Involvement for product design	0.72
Product innovativeness (α=0.80)*	
Extent to which the category already exists within a company	0.75
Extent to which the competitors were familiar	0.78
Extent to which the distribution system was familiar	0.50
Extent to which existing company plant and equipment were used	0.77
Extent to which the manufacturing process was familiar	0.91
Extent to which the technology for development was familiar	0.78

*The item measuring customer discontinuity was dropped due to low factor loading. I used 0.4 as a cut-off criterion.

** The two items measuring quality aspects of product performance were dropped due to poor uniqueness. The items have a uniqueness of 0.70 each, meaning that 70% of the variation in item 1 was not shared with item 2.

During the analysis I assessed the goodness of fit using the comparative fit index (CFI) – an index that reflects fit relatively well for all sample sizes. Values of CFI range from zero to one. A value of CFI greater than 0.90 was proposed as an acceptable fit for the data (Bentler, 1990). This indicates that the model can reproduce 90% of the covariation within the data. I also involved chi-square and root mean squared error of approximation (RMSEA) values. Chi-square values should not be significant if there is a good fit. While I included the chi-square values because it is a common test statistic, it is important to note that many authors believe the chi-square to be misleading in a number of circumstances, such as when ideal sample size and distributional requirements are violated (Worren, Moore & Cardona, 2002). Values of RMSEA range from zero to one, with values closer to zero indicating a better fit. By convention, there is a reasonable fit if RMSEA is less than or equal to 0.08. Moreover, the fit is good if RMSEA is less than or equal to 0.05. However, a CFA using Stata/SE 14.1 was run to assess the reliability and validity of my multi-scale constructs. A model was created that includes five latent variables: modularity, supplier involvement, product innovativeness (two constructs) and new product performance. The constructs were assumed to underlie specific observed variables which emerged from the literature. The results are $\chi2 = 196$, df = 179 ($p>0.19$), CFI = 0.98, RMSEA = 0.03. Since the construct supplier involvement is further operationalized in three latent variables, I provided the statistics for the three factor model supplier involvement. The results are relatively robust: $\chi2 = 25$, df= 21 ($p>0.25$); RMSEA =0.04 and CFI = 0.99. Thus, the results indicate adequate convergent validity among the instruments of each construct (Bagozzi & Yi, 1988). Furthermore, the correlations between the latent variables are all below 0.85 (Harrington, 2008). This, together with the Chi-squared test, indicate sound discriminant validity, i.e. this indicates that the constructs are separate factors (Kline, 1998). In summary, the described results support the overall validity of the research constructs used within this study.

3.4.2 Descriptive statistics

Descriptive statistics are displayed in Table 3. The basic statistics were obtained by averaging the relevant items. The table illustrates the means and standard deviations of modularity, new product performance and of the synthesized constructs of product innovativeness and supplier involvement. Product innovativeness and supplier involvement were operationalized in two and three latent variables, respectively. The variability in the measures of the constructs is reflected in the standard deviations. As can be observed, companies appear to be quite satisfied with their new product performance. Moreover, there seems to be a tendency towards modularity.

Table 3: Descriptive statistics of and inter-correlations between the variables.

Variables[1]	**N**	**Mean**	**S.D.**	**1**	**2**	**3**	**4**	**5**	**6**
				1					
1.Modularity	43	3.27	.90	1					
2. Communication	42	3.20	.16	17*	1				
3. Infrastructure	43	2.10	.06	.19*	.50**	1			
4.Design Involvement	43	2.86	.99	.19*	.68**	.42**	1		
5.Marketing Discontinuity	43	2.38	.18	0.23**	0.05*	0.06*	.03*	1	
6.Technological Discontinuity	43	2.38	.06	0.22**	.13	.05	.20*	.47**	1
7. NPP	43	3.46	.89	.09	.04	.07	0.05	0.30**	0.15

[1] The modularity variable consists of 4 items. The other variables consist of 3 items each.

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Note: This study used a 5-point Likert-scale with 5 implying a high estimation of the variable.

3.5 Findings

The scores of the constructs were used to test the hypotheses with a structural equation model analysis in Stata/SE 14.1. In the model analysis, maximum likelihood estimation and standardized regression weighting were used (Schumacker & Lomax, 1996).

Table 4 presents an overview of the hypotheses that were tested and their outcomes. Hypothesis 1 proposes that modularity has an inverted, u-shaped relationship with product innovativeness. In the model displayed in Figure 5, both “modularity” ($\beta = -0.36$, $p < 0.001$) and “modularity squared” ($\beta = -0.35$, $p < 0.001$) are negative predictors of technological discontinuity. Moreover, they are negative predictors of market discontinuity. The corresponding coefficients are β -0.31 and $p < 0.01$ for “modularity” and $\beta = -0.30$ and $p < 0.01$ for “modularity squared.” Thus, the influence on overall product innovativeness is negative. These findings only partially support hypothesis 1. Not only do exceedingly high levels of modularity have a negative impact on product innovativeness, but so do intermediate levels. For this reason, product classification, product type, type of reimbursement and regulatory procedure were used as control variables. The controls exhibit lower technological discontinuity for laboratory equipment and inactive implants compared with the reference group. The reference group encompasses product categories with low frequencies within the sample. The higher the familiarity of regulatory rules, the lower is the product innovativeness.

Table 4: Overview of hypotheses and findings.

Hypotheses	Findings
H1: Modularity has an inverted, u-shaped relationship with product innovativeness.	Partially supported
H2: Modularity has a positive relationship with new product performance.	Rejected
H3a: Technological discontinuity has a positive relationship with new product performance.	Rejected
H3b: Market discontinuity has a negative relationship with new product performance.	Supported
H4: Supplier involvement positively mediates the relationship between modularity and new product performance.	Rejected
H5: Supplier involvement has a positive relationship with product innovativeness.	Supported

Hypothesis 2 states that firms that apply modular product development practices will improve new product performance. However, this hypothesis was not supported. Products classified as Class II A and B products have a significantly higher new product performance than non-classified observations. The non-classified products represent the reference group.

Hypotheses 3a and 3b both examine the relationships between product innovativeness and new product performance constructs. The positive impact of technological discontinuity on new product performance cannot be supported. This finding is consistent with Calantone, Chan and Cui (2006). Furthermore, Class I, II A and II B products generally perform better than the reference group. For the factor market discontinuity, the data confirms the theorized relationship with new product performance. Indeed, the statistics support the negative impact of market discontinuity on new product performance ($\beta = -0.42$, $p < 0.05$). The more unfamiliar the market where the product is being sold, the worse is the financial performance of that product. Conversely, the higher the market familiarity of the product, the better is the new product performance. Product classification, product type, type of reimbursement and regulatory procedure were used as control variables.

To test hypothesis 4, both modularity and supplier involvement were set as independent variables and new product performance was used as a dependent variable. Once again the usual controls were used. The results reveal that modularity affects two out of the three sub-constructs of supplier involvement. Modularity affects the infrastructure and communication constructs. The corresponding coefficients are $\beta = 0.23$ and $p < 0.05$ for infrastructure and $\beta = 0.25$ and $p < 0.05$ for communication. However, the statistics do not suggest a direct, positive relationship between modularity and the sub-construct that measures design involvement ($p > 0.1$). Controlling for product type reveals that all of the sub-constructs are rated higher for electromechanical products compared with the reference group. Thus, the analysis indicates that there is no relationship between modularity and new product performance. Furthermore, no relationship between supplier involvement and new product performance was found. Controlling for product classifications reveals that Class II A and B products perform significantly better than the reference group. In summary, there are no direct or indirect effects of modularity on new product performance mediated through supplier involvement.

Hypothesis 5 suggests that supplier involvement has a positive relationship with product innovativeness. Only the two sub-constructs, communication ($\beta = 0.19$; $p < 0.05$) and design ($\beta = 0.23$; $p < 0.05$), have a positive relationship with technological discontinuity. The control variables exhibit significantly higher technological discontinuity for Class III products and lower technological discontinuity for inactive implants and laboratory equipment. There was no significant relationship between supplier involvement and product innovativeness in terms of market discontinuity.

3.6 Discussion and Implications

First this section examines the mediation model with product innovativeness as the mediating variable. Subsequently, this section discusses the mediation model with supplier involvement as the mediating variable.

3.6.1 Modularity, product innovativeness and new product performance

The statistics reveal that modularity has a negative impact on product innovativeness. Hence, the statistics only partially support the inverted, u-shape relationship found by Lau, Yam and Tang (2011). In fact, only the associated decrease in product innovativeness when modularity increases is supported. Modularized products seem to be counterproductive for technological and market discontinuity. The strictly specified, separated and standardized interfaces of the modules and architecture may restrict the freedom of designers to innovate. These interfaces are associated with a decrease in opportunities for designers to interact across different modules, thereby reducing cross-knowledge sharing for innovative ideas. The firms that apply a relatively high degree of modularity operate within familiar technological areas and involve familiar processes and technologies regarding development technology and processes as well as manufacturing equipment and processes. These findings are in accordance with Chesbrough and Kusunoki (2001), who have argued that new technology that implies a technological discontinuity should be captured integrally or holistically. Thus, capturing a new technology requires engineers to learn and accumulate technological knowledge on the entire product level and not only on the component level. However, I could not prove that engineers may simply adapt existing components to new innovative functionalities that result from distinct technologies. Furthermore, I could not support the idea that modularity leads to fast trial-and-error learning, which accelerates breakthrough innovation. Rather, modularized products appear to hinder innovation because of high product similarity and limited differentiation in new products. This finding adds to the discussion on what level of modularity a company should work. In fact, the ability to increase innovativeness by increasing the degree of modularity, found by Lau and his colleagues, should be discussed further. Indeed, managers who are interested in increasing the innovativeness of a product should monitor the level of innovativeness of their products against the degree of modularity. If it seems that product innovativeness is reduced, plus evidence of designers' confusion about too many design alternatives, they should cease further modularizing their products (Lau et al., 2011). Moreover, there are ways to diminish the negative effects of modularity on innovativeness. Firms may develop design rules to systematically reduce the number of alternatives during the development process (Baldwin & Clark, 2000). Furthermore, there is a design method to balance product similarity and differentiation (Robertson & Ulrich, 1998): Designers should distinguish product components that have the highest value for customers and modularize components that are common in various products.

Only product innovativeness, in terms of market discontinuity, suggests a relationship with new product performance. Developing modular products is associated with a decrease in market discontinuity, which has positive effect on new product performance. Market discontinuity is a lack of familiarity with the new product category, new competitors and new distribution channels. This implies that a high degree of modularity has an indirect, positive effect on new product performance. The higher the modularity, the more familiar the market and the better the new product performance. With increasing modularity, firms are able to remain within their market domain. In such a market, the firms know about the distribution channels, competitors and product categories and are successful competitors. However, when they sell the product in a more unfamiliar market, they may still be successful if they align their existing resources and skills to the unfamiliar market. In such a case, a firm must use its marketing skills and resources to address the new customers (Danneels & Kleinschmidt, 2001; Henard & Szymanski, 2001). Danneels and Kleinschmidt (2001) have suggested that it is not only important whether a firm sells in familiar markets, but also whether a firm is able to use its marketing skills and resources to address new customers. This implies that a firm that is able to address a new market with its current capabilities will be successful (Barney, 1991; A. Simon, 2012). Therefore, both familiarity and fit regarding market knowledge and marketing skills and resources suggest that launching a new product successfully is more likely to occur when the company is either familiar with the market or can adapt their skills and resources to the target market (Danneels & Kleinschmidt, 2001; X. M. Song & Parry, 1999). However, the present research only supports the familiarity relationship, since it did not consider the fit relationship. Therefore, future research should examine the same industry and attempt to determine robustness for the marketing fit argument.

The statistics indicate that modularity does not have a significant impact on new product performance. Thus, hypothesis 2 is not supported. From a pragmatic point of view, it is comprehensible that customers do not necessarily buy a product because of its modularization. From this perspective, the present study argues that a customer does not appreciate modularity. Although firms apply modularity, they do not take advantage of it in terms of financial advantage. Indeed, the benefits of modularity should be adapted to a firm's capabilities, subsequently improving the firm's performance (Worren et al., 2002). Moreover, the results may not exhibit improved firm performance because performance is aggregated at the product level. A new product development project may be unsuccessful even while the firm remains an adequate competitor. However, a majority of the research that relates the concept of modularity to new product performance derives from the automotive and electronics industries. Within these industries, modularity is often positively related to new product performance. I attempted to generalize the findings beyond the automotive and electronics industries, but could not determine a generalization within the medical technology and device industry.

3.6.2 Modularity, supplier Involvement and new product performance

It can be observed that modularity affects supplier involvement practices. Indeed, the higher the degree of modularity, the more that firms use commonly linked information systems, co-locate project personnel and use shared training programs. Moreover, the higher the degree of modularity, the more that firms allow key suppliers to participate in new product development teams, communicate with the suppliers and share design knowledge with them. However, the present findings do not support that such firms would simultaneously involve suppliers in design activities. Such activities would be the definition of architecture or product design and involvement in prototype design. While modularity creates opportunities for stronger collaboration with suppliers and learning across firm boundaries and facilitates supplier integration practices in new product development, it does not say in what kinds of activities or procedures firms should involve their suppliers. Thus, the results do not indicate that key suppliers are involved in the overall product design and engineering. However, firms that develop modular products do work closely with their key suppliers. This supports the idea that firms must engage in supplier relationships to develop modular products (Staudenmayer et al., 2005). Furthermore, no positive impact of supplier involvement on new product performance was found. This is contrary to Danese and Filippini (2013), M. Song and Di Benedetto (2008) and Sun, Yau and Suen (2010), but supports the findings of Bonaccorsi and Lipparini (1994), Danese and Filippini (2010) and Ittner and Larcker, (1997). In this study, none of the supplier involvement activities suggests a more successful product and thus, there is no direct relationship between modularity and new product performance. Consequently, modularity neither direct nor indirectly affects new product performance; A customer does not buy a product because it has been jointly developed with suppliers. Indeed, a customer does not appreciate supplier involvement or the corresponding positive impacts on a product.

Bruce, Leverick, Littler and Wilson (1995) have described the potential disadvantages and risks of collaborative development projects: leakage of information, loss of control or ownership, longer time-to-operation time, conflicts due to differing aims and objectives, loss of partner's commitment and higher development costs. Longer time-to-operation time and higher development costs are directly related to our financial construct. However, with regard to the present study, it can only be assumed that such negative impacts are associated with a decrease in the new product performance construct. In summary, manufacturers who adopt a modular design strategy cannot expect to improve their financial sales performance, but can except to facilitate supplier integration.

3.6.3 Product innovativeness and supplier involvement

Working together with key suppliers in new product development as well as involving them in design activities enhances product innovativeness. This is in agreement with other research (Chesbrough, 2005; Henke & Zhang, 2010; Sun et al., 2010). Supplier involvement specifically is associated with an increase in the newness of processes or technologies associated with the development technology, development processes and manufacturing equipment and processes. Hence, such a product is more innovative in terms of technology. Indeed, the product itself becomes more innovative. Moreover, supplier involvement enables technological discontinuity and correlates to product innovativeness. Therefore, managers who want to improve product innovativeness may rely on innovative inputs from suppliers. Consequently, they should involve key suppliers in new product development processes as well as in design activities: defining the product architecture, setting design specifications and designing the product. From such activities, companies may take advantage of technological newness.

However, suppliers do not influence the buyer's decision within which market to sell the new product. Hence, supplier involvement does not influence market discontinuity. As such, supplier involvement may not be sufficient enough for manufacturers to cross industry borders. Component suppliers have similar knowledge about the product architecture as manufacturers and bring technological novelties that only concern the actual market.

3.6.4 Product types

For the analysis, I used different controls on the exogenous variables. For example, two dummy variables that control for the new product performance construct were found to be significant. The dummies have a value of one for Class II A and B products, respectively. The results further indicate that Class II A and B products perform better than the reference group. Although the reference group consists of non-classified products, the products are still medical technology devices. The reference group consists of product categories with relatively low frequencies within the sample. Moreover, Class III products have a significantly higher technological discontinuity than the reference group and inactive implants have a significantly lower technological discontinuity than the reference group. Finally, firms that develop electromechanical products involve their suppliers to a greater extent. Thus, it can be observed that variance within the constructs' new product performance, supplier involvement and technological discontinuity can also be explained by various product characteristics or classifications. Further research should thus examine the product categories separately.

3.7 Conclusion and Limitations

3.7.1 Modularity and innovativeness

This study analyzes the implications of modularity on new product performance and relates both constructs to supplier involvement and product innovativeness. Increasing the degree of modularity lowers product innovativeness in the form of market and technological discontinuity. It appears that developing modular products does not positively impact the innovativeness of these products. However, modularity is an important concept for incrementally or modularly improving existing products. The results reveal that improving existing products based only on incremental or modular innovation does not refer to capturing new technologies or serving new markets. For capturing new technologies or serving new markets, companies might holistically rethink the overall product. For example, including new technologies from distinct fields may lead to architectural innovation that can no longer be managed within an established product architecture (Henderson & Clark, 1990). Gaining architectural knowledge of the new product is related to understanding the new architecture.

3.7.2 Modularity and supplier involvement

Increasing the degree of modularity facilitates supplier involvement within new product development in the form of increased participation and communication with key suppliers. Supplier involvement, in turn, enhances product innovativeness in the form of applying unfamiliar processes and technologies with regard to development technology and processes as well as manufacturing equipment and processes. On the one hand, modularity is associated with a decrease in product innovativeness, while on the other hand, it is associated with an increase in technological discontinuity through supplier involvement. Thus, it can be seen that collaboration practices between manufacturers and suppliers may lead to a discontinuity in technology that seems to be captured within a new product architecture (Bozdogan et al., 1998; Brusoni et al., 2001; Henke & Zhang, 2010) that is characterized by new components and interactions between the components and hence, new architectural knowledge. Such new knowledge is tacit and must be accumulated in an integral way that requires rethinking the entire product (Chesbrough & Kusunoki, 2001; Nonaka & Takeuchi, 1995), while changing the established architecture. Future research should more closely examine the interactions between modularity, supplier involvement and product innovativeness in a case study. Case study research would enable the underlying processes to be fully understood.

Interestingly, I did not find either a direct or indirect relationship between modularity and new product performance. Other more important factors contribute to new product performance. Thus, it may be interesting to analyze how fit a company is with regard to regulatory methodologies. Recent evidence has suggested that regulatory and procedural knowledge is more important than technical knowledge for predicting firm success within the medical technology and device industry (Stern, 2015). Therefore, future research could include fit, with regard to regulatory rules, and relate it to product development performance while also considering the other concepts.

Although companies apply modular design principles and involve suppliers in product development, such successful methods or activities discussed within the literature are not related to new product performance. Moreover, modularity and supplier involvement in new product development are not important factors for adequate new product performance. Supplier involvement may not be sufficient for adequate new product performance. For this reason, it is likely that regulatory rules within the medical technology and device industry play an important role (Stern, 2015) that has not been comprehensively examined within the present research.

Serving familiar markets appears promising for medical technology companies, i.e. launching a product in a familiar market may lead to relatively high new product performance. Indeed, serving unfamiliar markets is only successful when companies can adapt their skills and resources to serve such a market (A. Simon, 2012). Future research should more closely examine the interactions between market discontinuity, marketing fit and new product performance to understand the implications on new product performance.

3.7.3 Industry convergence

Industry convergence is characterized by the ability of technology to blur industry borders (Brusoni et al., 2009). Technologies that cross industry borders are characterized by companies rethinking the overall product design. Indeed, new technologies may force companies to entirely rethink their product architecture (Fleisch, 2016; Henderson & Clark, 1990). This implies that new technology cannot be captured within an established architecture. My results support the argument that no positive relationship exists between modularity and technological and market discontinuity. Thus, firms affected by industry convergence should begin holistically rethinking their product conceptualization, since new technology may not be captured within the established design. It appears that modularity leads to new products with limited differentiation. Moreover, differentiated, new technology may originate from relatively intensive supplier involvement practices within new product development. However, it also seems that such a technological discontinuity may not be captured within an established product architecture. Therefore, firms should begin collaborating with various actors (suppliers, customers, universities, research centers, etc.) from distinct fields while simultaneously developing modular products. Collaborating and sharing knowledge with actors from distinct technological fields may help firms understand the new architecture that involves new technology from a distinct field more quickly or create a breakthrough innovation. While socializing with distinct technologies, companies may already begin the process of knowledge creation through sharing tacit knowledge across and among various actors (Von Krogh et al., 2000). Socializing involves sharing tacit knowledge about new technologies from distinct fields across and among different actors within and across the industry boarders.

3.7.4 Limitations

Other research has often aggregated corresponding items on the firm level. Thus, within the present study, this disparity may have led to different results. If the questions had been aggregated on the firm level, respondents would have provided their opinions of overall company performance as well as the performance of a specific product. In this way, a specific development project may be relatively unsuccessful while the overall company may still be considered a sound competitor. Therefore, I might have a lower score for my performance construct than similar studies. Moreover, modularity and supplier involvement activities may not necessarily be successful on the product level, but on the company level, since the strategies are aggregated on the company level. Thus, future research should differentiate between the two levels for clarification on the performance construct.

I used a single key informant for data collection: The assumption being that a senior manager is, by virtue of the position within the company, capable of providing opinions that reflect the company’s behavior (Philips, 1981). Therefore, the potential problems of respondent bias and content validity require additional research. Thus, a multiple informant approach in the form of a case study research could be adopted. Moreover, the study had the usual limitations inherent within a research design that employs single respondents and subjective measures. Although both type one and type two errors were possible, the risk of a type two error – not detecting a true population relationship – was likely highest given the sample size[12] and research design. This research is a description of actual causes and effects and not a test of the potential future benefits that firms may gain from modularity. Power is a function of effect and sample size; Small samples may suffer lack of power. The implications

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[12] Two measures of the overall fit of the model take into account sample size (RMSEA and CFI).

of this research are that the null results related to new product performance may have been due to the sample size.

Furthermore, since this study uses a large set of variables, I was limited in the number of items I could use to measure each variable due to restrictions on the length of the questionnaire. This probably decreased the present study’s construct validity when compared to more complete scales. Finally, another potential limitation relates to the single industry focus. Nevertheless, a wide range of product categories characterized the sample. This heterogeneity suggests that the research results may be more globally applicable than is typically the case for a single case industry.

Chapter 4 Previous Industry Membership and the Conceptualization of Product Features: The Case of Nascent Smartwatches

4.1 Introduction

The Swiss watch industry is one of the largest export sectors in Switzerland (Trading Economics, 2016) and the main player on the global watch market in terms of sales (Smith, 2014). Indeed, the label "Swiss" is a global sign of outstanding quality and reliability that covers several hundred years of watchmaking history (Terasaki & Nagasawa, 2014). The recent rise of the product market for smartwatches has evoked discussions about its impact on the Swiss watch industry (Deloitte, 2016; Henkel, 2016; Raffaelli, 2014), especially the Apple Watch launch in 2015 (Apple, 2015). A smartwatch is a wristwatch that may be connected to other devices and provides extra features. Smartwatches provide computer functionality, connectivity, sensor and actuators (Eidgenössisches Institut für Geistiges Eigentum, 2016; "Interview: Watch Industry Research Experts," 2016). The smartwatch's ability to connect to a device like a smartphone and use mobile infrastructures like apps opened up opportunities to develop extra features (Lyons, 2016). Companies like Apple, Fitbit, Xiaomi and Garmin are key players in the smartwatch market[13]. Apple and Xiaomi are consumer goods companies and Garmin and Fitbit have a background in sports tracking solutions. Additionally, Swiss watch companies have launched smartwatches and have an industry background in traditional watchmaking. The mentioned companies, including the Swiss companies, compete in the nascent smartwatch market but are firms from previously distinct domains. A nascent product market is characterized by fleeting product characteristics, market boundaries and user needs (Aldrich & Fiol, 1994; Lounsbury, Ventresca & Hirsch, 2003; Santos & Eisenhardt, 2009). During such periods of shifting industry boundaries, firms try various product configurations, functions and technologies (Benner & Tripsas, 2012). Potential customers do not have a lot of experience with the nascent product and thus, cannot yet articulate their personal preferences (Benner & Tripsas, 2012). Firms experiment with alternative product configurations, functions and technologies. This experimentation with competing product alternatives often converges on a dominant design. A dominant design is a standard set of technologies and interfaces

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[13] Apple sold almost 12 million Apple Watches in 2015. Fitbit and Xiaomi have sold 21 and 12 million units respectively.[13] The Swiss watch industry sold 28.1 million watches in the same time period. For Swiss watch companies that have smartwatches in their product portfolio, smartwatches account for roughly 10% of total volume sold - numbers are estimates of the Vontobel report (Vontobel, 2016).

and the emergence of such a design marks a point in time when firms agree about what performance attributes are important (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Clark, 1985).

4.1.1 Research gap

While the general evolution of a dominant design has been well studied (Abernathy & Clark, 1985; Anderson & Tushman, 1990; Clark, 1985; Murmann & Frenken, 2006; Suarez, 2004; Suarez, Grodal & Gotsopoulos, 2014), management scholars lack an understanding of the dynamics of a nascent product market (Benner & Tripsas, 2012). First, scholars have mainly examined the emergence of a dominant design according to technologies embodied within a product (Murmann & Frenken, 2006). Murmann and Frenken (2006) conducted a literature review about the emergence of dominant designs in terms of the technologies incorporated within dominant designs. However, the eventual convergence on a dominant design is a twofold process that incorporates both a technological and market variable (Clark, 1985) – both technological and market characteristics converge on a dominant design. The market variable of the process covers the initial variance in product features. Thus, a robust understanding of how initial differences in product features may influence the possible convergence on a dominant design that incorporates a standard set of standard features does not yet exist (Benner & Tripsas, 2012). Therefore, examining the initial differences of product features in a nascent product market is important to understanding the initial dynamics of the evolution of dominant designs and how nascent industries evolve. Second, researchers have mainly focused their attention on examining what types of companies enter a nascent product market and on questions about the timing of the entry (Klepper & Simons, 2000), but have not focused their attention on discussing firm heterogeneity and the corresponding choice of nascent product features. Indeed, converging firms with distinct backgrounds that compete against one another in a new product market may provide an opportunity to examine firm heterogeneity and its impact on the choice of nascent product features. Management literature further lacks an understanding of how the prior industry affiliation of entrants influence their decision on nascent product features (Benner & Tripsas, 2012). Understanding such mechanisms is important to understanding customers' buying behavior and the emergence of a nascent product market (Rindova & Petkova, 2007).

This study discusses both gaps within the literature by illustrating how the background of Swiss watchmaking companies affects the decision on what product features are incorporated in a product for a nascent product market. A firm's background is conceptualized by a firm's previous industry membership. Research has suggested that a firm's previous domain presumably influences the definition of initial product features due to capabilities, beliefs and imitative behavior. Thus, firms are likely to launch products that leverage the firm's main strengths (Helfat & Raubitschek, 2000). A nascent product market is characterized by high ambiguity. Therefore, socio-cognitive factors may influence managers who are trying to make sense of confusing and conflicting signals (Weick, 1990). Consequently, beliefs from a firm's previous industry experiences influence managerial decisions (Tripsas & Gavetti, 2000). Moreover, managers imitate behaviors of projective firms during times of high uncertainty (Rao, Greve & Davis, 2001). Firms that analyze, interpret and conceptualize products within a nascent product market are influenced by their prior industry experience. Benner and Tripsas (2012) have suggested that product features and concepts of digital cameras and expected usages vary systematically depending on a firm's background. Their results reveal that firms from the same prior industry have similar assumptions about what consumers value. The similar beliefs are reflected in their concurrent introduction of similar features. The present research adds to this discussion by examining the conceptualization of nascent product features within the nascent smartwatch market and how a company's industrial background influences the conceptualization. Moreover, this paper explains how the Swiss watch industry has reacted to the evolving smartwatch market by examining their nascent product conceptualization.

This chapter is structured as follows: First, it illustrates the history and the market of the Swiss watch industry. Subsequently, the study introduces the smartwatch market and explains how Swiss watch manufacturers have entered the market by examining their conceptualization of nascent smartwatch features and comparing their conceptualization to key players' conceptualizations. Finally, this chapter concludes and provides suggestions for future research.

4.2 Theoretical Setting

4.2.1 Evolution of Industries

The concept of a dominant design was first discussed by Abernathy and Utterback (1978). A dominant design is the architecture of a product that establishes a certain dominance within a class of products (Abernathy & Utterback, 1978). Henderson and Clark (1990) and Tushman and Murmann (1998) have characterized dominant designs by a set of core design concepts incorporated in components. These components correspond to major functionalities performed by the product. Furthermore, the product architecture defines how these components are integrated and interact with each other. For example, in the early days of the smartphone industry, smartphones were expected to integrate Wi-Fi functionality. Furthermore, as the technology continued to evolve, a smartphone needed to implement a touch screen – a feature that only a number of years earlier was not needed for a smartphone to be considered a legitimate member of the smartphone market (Suarez et al., 2014).

Studies that discuss the evolution of industries which face large changes in technology have documented three stages of progress: a stage of fuzzy dominant designs, a stage of convergence on a dominant design and an era of incremental change (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). The first stage is characterized by changing and fleeting product characteristics, market boundaries and user needs (Aldrich & Fiol, 1994; Lounsbury, Ventresca & Hirsch, 2003; Santos & Eisenhardt, 2009). In this phase, customer needs are changing (Clark, 1985) and the comprehension of the industry's stakeholders (e.g. customers, producers, critics and regulators) is changing and remains unclear (Kennedy, 2008). Moreover, potential customers have little experience with products and their preferences and needs are therefore, undefined. Additionally, ideas about the definition of the product and how customers should use it are unclear. The technologies embodied in the products also remain uncertain and firms are unsure about the rate of improvement of the product's performance as a result of the new technology. Furthermore, firms are unsure about how components of the nascent product interact with one another and about whether the technological possibilities will work or not (Aldrich & Fiol, 1994; Garud & Rappa, 1994; Lounsbury et al., 2003; Santos & Eisenhardt, 2009). Uncertainty about the market and technology often accompany uncertainty about the competitive landscape since firms face shifting industry boundaries and new competitors from previously distinct industries (Brusoni et al., 2009). During this period of time, firms experiment with alternative product configurations, functions and technologies. Eventually, competing alternatives may converge on a dominant design, which establishes dominance among competing design paths (Suarez & Utterback, 1995).

Competitors do not always converge on a dominant design. When they do converge, however, the dominant design reflects both technological and cognitive convergence. Technological convergence indicates a consensus about a set of standard technologies, modules and interfaces (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). The cognitive convergence is characterized by a common understanding of what the product is, how the product may be used and what core attributes will have value (Kaplan & Tripsas, 2008). Furthermore, scholars have extensively studied the potential convergence on a dominant design on the basis of technological development. For example, Murmann and Frenken (2006) have described five causal mechanisms that explain the emergence of a dominant design. First, a dominant design becomes standard or dominant because it is simply the best technological compromise among the various different functional characteristics of the technology. Such an emergence is a result of the search for improvements. Second, with standardized products a company is able to realize economies of scales. Third, while implementing a particular dominant design it is possible to take advantage of the concept of network externalities. In this case, the value of changing to a particular design depends on the number of users who bought a compatible technology. Fourth, the design that initially gains the majority of the market share will often become the dominant design because of self-reinforcing processes. In this case, it is possible to license your product to many other companies. For example, Cusumano, Mylonadis and Rosenbloom (1992) have determined that the strategy of Victor Company of Japan (JVC) of licensing Video Home System design to other firms is the main factor that contributed to JVCs success over Sony's design. The fifth mechanism emphasizes that the emergence of a dominant design is explained through a combination of sociological, political and organizational dynamics. However, as soon as a dominant design has been developed, products may still be differentiated and firms typically compete over product quality and reliability as well as brand and new peripheral features (Utterback, 1994). The listed mechanisms assess the emergence of a dominant design while focusing on the technology incorporated within the products. Additionally, Henderson and Clark (1990) have argued that a change in the architecture of a product may trigger a change in a component that creates new interactions with other components within a dominant design. They have further identified the case of a portable, transistor radio receiver as a type of innovation that changes the architecture, but does not change the components and the core design concepts. The portable radio receiver is not only an innovation based on a change made to the product's architecture, but it also incorporates the possibility to carry the product and use it in different places. This possibility can be viewed as a new product feature. Assumptions about customer needs and usages may have influenced this decision on the overall product design. Similarly, Christensen, Suárez and Utterback (1998) studied the hard disk drive industry and have determined four distinct product architectures that comprise the eventual dominant design: Winchester Architecture, Pancake Motor at Spindle Base, Rotary Voice Coil Actuator Motors and Embedded Intelligent Interface Electronics. However, features that are associated with different ideas about customer preferences are not considered within their analysis. Thus, the research has mainly focused on examining the emergence of a dominant design in terms of technology, ignoring the market variable. Indeed, examining the product features of a nascent product market helps to understand how entrants develop their understanding of a new product market.

Another research gap is that management scholars lack an understanding of the how firms from previously distinct domains conceptualize products in a nascent product market (Benner & Tripsas, 2012). In general, scholars have argued that new firms are important for entry and innovative technologies (Martin & Mitchell, 1998; Tushman & Murmann, 1998). However, the extant management literature lacks an examination of whether and why distinct firms launch new products for a nascent product market with different product features. Benner and Tripsas (2012) have discussed the role of firm background. while explaining systematic differences in early product variants. Other studies have mainly discussed whether firms enter a market, when they enter and whether they survive (Dowell & Swaminathan, 2006; Martin & Mitchell, 1998). Other prior research has mainly discussed variations in resources and capabilities and how such differences explain the differences in firms' strategic behavior (Klepper & Simons, 2000). For example, producers of radios that had capabilities similar to those required to fabricate televisions were more likely to enter the television receiver industry and survive (Klepper & Simons, 2000). Researchers have not focused enough on examining how prior industry membership reflects shared beliefs and experience. This is important since an understanding of the influence of prior industry affiliation on the conceptualization of nascent product variants is needed, given the increasing competitive convergence of firms from previously distinct industries (Brusoni et al., 2009).

4.2.2 Conceptualization of a product for a nascent product market

Similar experience from a prior industry and continued interaction within the nascent product market engender common beliefs for members of the same industry (Huff, 1982). Huff has indicated that common beliefs comprise shared views, including common beliefs about customer preferences, future level of industry demand and role of regulation. Indeed, managers adapt common ways to examine circumstances that are shared widely across their industry (Spender, 1989). Similarly, Porac and Howard (1990) have defined typical common beliefs concerning competition, customers, suppliers and retail that have been developed over time by mangers from the same industry.

However, industry-wide beliefs are essential since they impact the decision-making process and thus, how firms take action (Levitt & March, 1988). Interestingly, firms apply common understandings, expectations and assumptions when they enter an uncertain, nascent product market with new technologies and new usages (Benner & Tripsas, 2012). In such an environment, executives are not yet aware of what customers want and for this reason, they can only assume how customers will use the product and what product functionalities will be successful. Benner and Tripsas (2012) have argued that the mechanism of how companies of the same prior industry apply shared assumptions is twofold. First, managers apply beliefs about prior situations to new situations that are assumed to be similar (Gavetti, Levinthal, & Rivkin, 2005; Gavetti et al., 2005). A company’s experience with customers in the prior industry may create expectations about what customers value in the nascent product market. Second, companies from the same prior industry continue to interact with one another while sharing information about the nascent product market since companies are more likely to interact with and observe familiar peers (Ocasio, 1997). These processes may lead to a common understanding, expectations and assumptions of firms from the same prior industry. Therefore, companies from the same prior industry are likely to incorporate similar product features within a nascent product market.

The following section describes the methodology of the research.

4.3 Methodology

I chose to employ an exploratory, qualitative research design. A qualitative research design examines a phenomenon that is not well understood and illustrates the context within which the phenomenon exists (Yin, 2003). The initial idea was to conduct a case study research in several companies so as to obtain empirical evidence from real people within real organizations (Myers, 2009). However, many Swiss watch manufacturers, especially the ones from the two leading groups were exceedingly reluctant to discuss the subject. For example, a watch director wrote in an Email that the topic (ongoing smartwatch projects) is too delicate to discuss ("Written Answer: Watch Director," 2015). An executive manager of a large watch-making group in Switzerland further stated that none of the staff were allowed to discuss smartwatches when the Apple Watch was launched ("Interview: Swiss Watch Vice President," 2015). Furthermore, other companies claimed to be extremely busy because of ongoing smartwatch projects and therefore could not talk. For these reasons, I slightly adapted my research design, but still chose a qualitative and exploratory research design which relied upon primary and secondary data (Heaton, 2008).

4.3.1 Data

One source of information was primary data in the form of semi-structured interviews, phone calls and personal e-mails. Such data was primarily collected from senior managers or higher ranking professionals at Swiss watch manufacturers or industry R&D centers. For the semi-structured interviews, respondents answered in face-to-face and group interviews and one manufacturer hosted a facility visit. The primary data was collected over a 12-month period from March 2015 until March 2016. The purpose of the interviews, phone-calls and personal e-mails was to gather expert information within different companies. The interview protocol was based on a company's understanding of the smartwatch market, the value proposition of traditional Swiss watches and smartwatches and why and how companies react or not react in the form of launching their own smartwatches.

The other source of data was secondary data (Popay et al., 1998). The secondary data helped create more specific questions for the semi-structured interviews. Secondary data was gathered and recorded by someone else prior to and for a purpose other than the current project (Vartanian, 2011). The secondary data did not try to examine a common subject under study by conducting systematic literature reviews, but rather used existing data to study a new research question (Popay et al., 1998). I used secondary data from various sources such as books, magazines, newspapers, webpages, speeches of industry executives, organizational records and archives, e-mail correspondence and journals (Research Starters, 2016); I also involved works from professional scholars to journalists (Storey, 1999). To obtain information about the Swiss watch market, I relied on archival data from the Federation of the Swiss Watch Industry and Bank Vontobel. However, I could not be confident about how the secondary data was collected, samples were selected or about the relevance of measurements to the primary research (Research Starters, 2016).

4.3.2 Empirical setting

The field under study is the nascent smartwatch market, with a focus on Swiss smartwatch producers. The Swiss watch industry is the global leader in watchmaking in terms of sales and is one of the country's strongest industrial sectors (Botteron et al., 2015). The nascent smartwatch market has shifted industry boundaries, including the boundaries of the Swiss watch industry. The emergence of the smartwatch market is characterized by the entry of firms from various industries. These firms originated in the watchmaking, computing/consumer electronics or sports industries and although they currently compete in the nascent smartwatch market, it is important to bear in mind that they are firms from previously distinct domains. This important fact makes it possible to compare the influence of firm background on decisions regarding what features a smartwatch should include.

4.3.3 Analysis

I began by studying the Swiss watch industry through a literature review about the history of the Swiss watch industry. This included a statistical analysis of the current market structure. I simultaneously applied content analysis techniques, while transcribing and analyzing the primary data and secondary data. Furthermore, I visited several companies and research centers and learned about their comprehension and apprehension of the smartwatch market. During these visits, I conducted interviews with senior managers or higher ranking professionals at Swiss watch manufacturers or industry R&D centers. The interviews lasted between one hour and 90 minutes and were taped, transcribed and analyzed together with the secondary data using content analysis techniques. In this way, I could gather different views on the smartwatches and their potential impact on the Swiss watch industry. The data was analyzed using qualitative data analysis techniques that involve coding themes and keywords. I was searching for patterns in the themes to better understand the main themes and basic concerns of the interviewees (Miles & Huberman, 1994). Consequently, as well as looking for common themes, ideas and suggestions about the apprehension and understanding of smartwatches (including the decision on what product features to incorporate in a nascent smartwatch) within both the primary and secondary data (Hsieh & Shannon, 2005).

4.4 Swiss Watchmaking

This section documents the history of the Swiss watch industry and briefly discusses the economic downturns experienced within the industry and the corresponding reactions.

4.4.1 Early days

The Swiss watch industry originated in the mid-16th century due to the Reformation in Geneva. The reformer Jean Calvin prohibited wearing jewelry. Consequently, goldsmiths and other jewelers changed their business model and started to produce mechanical watches[14] instead. However, the Swiss watch industry only became a global leader in mechanical watch production in the 18th century. The industry initially consisted of small family owned enterprises that participated in Swiss schools and society events, which eventually led to a culture of Swiss watch fabrication and innovation. The U.S. watch industry challenged the Swiss watch industry with new production systems that came about as a result of industrialization at the end of the 19th century. Indeed, Americans had developed tools to produce watches at high volume, low cost and with low skills while retaining satisfactory levels of precision. They simplified watch movements and were able to introduce a more economical form of production. Work done by hand became less present within the production process and as a consequence, less skills were required to produce a watch. The Swiss industry was able to respond while adopting parts of the American production system (Landes, 1979). The Swiss industry changed to hybrid forms of production systems: Standardized components were manufactured in large centralized factories and decentralized firms maintained design and assembly activities, allowing for greater flexibility (Glasmeier, 1991). During the 1910s, Swiss mechanical watches dominated the world watch industry (Knickerbocker, 1976).

4.4.2 Export and manufacturing permits

World War I created deflation and disruptions that hit the Swiss watch industry hard (Raffaelli, 2013). Exports decreased by 48% and the number of unemployed workers in the watch industry increased to 3,000 individuals between 1916 and 1921 while sales dropped by one half from 1920 to 1921. The overall crisis led to price wars and opportunism within the Swiss watch industry. The impact of World War I and the resulting opportunism within the industry resulted in the formation of a cartel (Glasmeier, 1991). The purpose of the cartel was to preserve the Swiss industry’s small and medium sized enterprises. Various associations were created to represent the Swiss watch industry’s interests. The Swiss Watch Industry Federation was established to govern firms. The 17 manufacturers of watch movements were organized into Ebauches SA. Manufactures other than ébauches (clockworks) were organized into the Union des Branches Annexes de l’Horlogerie (UBAH) or the Societe Suisse pour l’Industrie Horlogere (SSIH), founded by the manufacturers Tissot and Omega.

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[14] A standard mechanical watch has more than 100 components assembled in three subassemblies (Federation of the Swiss Watch Industry FH, 2016). The subassemblies are the energy source, the regulating parts and the display. A spring stores energy and supplies the energy to the gear-train that moves the hands. The spring loses energy while the watch is running. Hence, the watch must be wound. The mechanical technology of watches remained stable until the 1960s.

The members of the various interest groups agreed to set prices and limit the production volume. Moreover, all exports required official permits and explicit rules were designed to restrict exports of parts (Landes, 1979). Due to the Swiss industry's relatively large share of national GDP and the continued opportunistic behavior of firms, the authorities forced greater coordination among industry actors while buying a large share of the main manufacturers (Glasmeier, 1991). Together with the industry and banks, the Swiss government created the holding Allgemeine Schweizerische Uhren AG (ASUAG), a final merger of Ebauche and the other manufacturers, to halt exportation.

Swiss manufacturers were only allowed to buy from non-Swiss component producers if prices were 20% below Swiss levels and the component producers were only allowed to sell to Swiss firms during a time period of approximately 30 years. Furthermore, the government regulated machinery sales and the production volume of Swiss watches while requiring permits for the construction and extension of production sites. The cartel, composed of almost 400 firms, was considered one of the most robust and efficient in economic history (Glasmeier, 2000; Landes, 1979). Swiss companies were not allowed to export parts or technology and manufactures were not allowed to build production facilities abroad. The export and manufacturing permits held supply below world demand and ensured that the Swiss firms achieved relatively high profit margins (Pasquier, 2008). Until 1961, the Swiss watch manufacturers and parts suppliers enjoyed relatively sound stability and steady growth (Glasmeier, 1991).

4.4.3 Worldwide competition and the quartz crisis

After three decades of stability and growth, foreign competition ended the Swiss cartel on mechanical watch production and the consequent quasi-monopoly on the global watch industry (Glasmeier, 1991). As a result, Swiss shares on the global market decreased. The liberalization that occurred in the 60s questioned the controlling role of ASUAG. Moreover, the rise of the quartz watch[15] in the late 60s and 70s fundamentally changed the global watch industry (Anderson & Tushman, 1990). In 1962, the Centre Electronique Horloger (CEH) was founded to produce quartz watches in Switzerland: 20 firms (including ASUAG, Omega, Tissot, IWC, Jaeger-LeCoultre, Mido and Rolex) participated in the consortium. The purpose was to have a quartz watch ready as soon as the market would demand one. Interestingly, CEH was the first to create a quartz watch in 1967 (Stephens & Dennis, 2000). Seiko also launched a compact quartz movement within the same year and Longines followed in 1969. Other Swiss and international watch manufacturers followed. A quartz watch is much more accurate and lighter than the most accurate mechanical watches (Epson, 2015). For example, the first Seiko quartz

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[15] A quartz watch consists of an integrated circuit. The division of time is effected by a quartz oscillator, which vibrates under the effect of electrical energy supplied by a battery. The electric current causes the quartz inside to pulsate with a precise frequency. The frequency is broken down through an integrated circuit where power is released through a small stepping motor that sets the watch hands in motion.

watch was accurate to ±5 seconds a month, while a mechanical Patek Philippe was only accurate in the range of -3 to +2 seconds a day. Suddenly, it was possible to produce not only more accurate watches but ones that were thinner and cheaper as well ("Interview: Swiss Watch CEO," 2015). In this instance, functional benefits such as price and performance prevailed over the competition. For decades individuals assumed that the precision of a watch was reflected in its price. The Swiss intended that since quartz watches are more accurate they would always be a more expensive alternative to mechanical watches. However, Japanese manufacturers were able to cut the average cost of a quartz watch by a factor of 100 (Breiding, 2012). Moreover, Swiss watch manufacturers did not think that quartz technology had much in common with their long tradition of precise watchmaking and craftsmanship (Landes, 1979). Indeed, they did not understand that the traditional mechanical watchmaking would have to radically change for the field to survive. Donzé (2011) has argued that the Swiss production system was too fragmented for improvements to be made to increase the productivity and quality of mechanical watch manufacturing. While highly coordinated production and distribution systems were important characteristics until the quartz crisis, they did not promote technological progress (Raffaelli, 2013). Swiss watch manufacturers were unable to compete with lower cost Japanese quartz watches. Consequently, around one half of the jobs (approximately 60,000) in the watch sector were lost until the early 1980s (Jaberg, 2016). Thus, 2/3 of the Swiss watch companies (roughly 1,000) disappeared (Raffaelli, 2013).

4.4.4 Birth of the Swatch Group

In 1980, the Société Suisse de l'Industrie Horlogerie (SSIH) – a large holding company that included brands like Omega, Tissot, Rayville-Blancpain and Hamilton – was no longer able to pay its December salaries and annual bonuses (Breiding, 2012). More than 100 banks bailed the company out while an independent firm of consultants was asked to examine and help the Swiss watch industry. Hayek Engineering from Zurich was asked to elaborate mitigation measures. Nicolas G. Hayek, the founder of the company, was responsible for the project. He proposed to merge ASUAG and SSIH into one holding company, the Société Suisse de Microélectronique et d'horlogerie SA (SMH). In 1983, they started to implement the merger and the years until 1986 were a transition period of implementation. One aim of this project was to extend the strategy to a portfolio of lower priced watches. The success of the Swatch watch illustrates the differentiation towards lower price segments.

4.4.5 Swatch

Indeed, the SMH needed to differentiate and was able to do so through the marketing of the Swatch watch (Breiding, 2012; P.-Y. Donzé, 2011; Raffaelli, 2013). In 1983, Swatch was launched in Switzerland (P.-Y. Donzé, 2011) and enjoyed increasing popularity worldwide until the end of the 1980s. Scholars and journalists generally describe the Swatch as a product innovation that played a major role in the comeback of the Swiss watch industry (Carrera, 1992). To design the Swatch watch, SMH relied on outside designers. The Swatch would be sold in traditional watch boutiques but the watch design would change seasonally. Swatch watches would be produced in many variations and the idea was to have a new and exciting brand. The SMH produced the Swatch on one automated production line, without needing workers to assemble the watch (Raffaelli, 2013). With the Swatch launch it became obvious that the Swiss were able to produce cheap quartz watches as well. Indeed, Swatch production costs decreased by 80% and required 55% less parts than a typical mechanical watch. By 1984, SMH experienced a profit margin of roughly 5% of gross sales.

P.-Y. Donzé (2011) examined how much of the success of SMH was due to Swatch sales. However, only information about the share of non-metal watches exported was available[16] to conduct such an examination. However, Swatch watches do have an important share in this category considering the growing volume of exports after the launch of the Swatch in 1983 (P.-Y. Donzé, 2011). Sales of non-metal watches totaled 13.4 million Swiss Francs in 1983, 225.9 million CHF in 1985 and 798.7 million CHF in 1993. Then from 2000 to 2009, it stagnated at an average of 297.6 million CHF. The maximum sales accounted for 22.8% of SMH's gross sales during the peak years of 1990 to 1995 (P.-Y. Donzé, 2011). From Donzé's analysis, it can be seen that more than 75% of gross sales cannot be explained by Swatch sales and hence, require additional reasoning. He has argued that a major portion of the remaining success of SMH and overall Swiss watch industry is due to the adaption of the production systems and a new marketing strategy.

4.4.6 New production system and marketing strategy

The production system based on multiple family owned enterprises was adjusted by centralizing the production of movements and parts and globalizing the general production system. The aim of this was to cut the number of models, increase the interchangeability of parts and automate production. This led to an aggregation of tasks (like production) at the level of the holding company. The enterprises of the two holdings were grouped together into three sub-holdings. Production facilities, operations and the management of the two holdings were merged to achieve greater economies of scale for the entire Swiss watch industry. For this reason, Omega, Longines and Rado no longer their own movements, but instead all purchased their movements from the same movement producer. The SMH acquired Swiss and international subcontractors (like watchcase and crown maker) and opened production plants in Asia and the US. Furthermore, the SMH and other Swiss companies wanted to strengthen the control of parts supply with a vertical integration strategy. Other small and medium sized companies followed the strategy of opening production subsidiaries in Asia. The SMH production

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[16] Non- metal watches from other brands, metal lines of the Swatch segment and Swatch watches sold in Switzerland are not included in the numbers.

sites around the world were intended to supply the holding's firms as well as the world market with quartz watches. Donzé (2011) has provided a detailed description of the production network.

In addition to restructuring the production system, SMH implemented a new marketing strategy. They created distribution firms that were responsible for all of the groups brands on the principal markets (P.-Y. Donzé, 2011). The idea was to have one distribution company per market. This helped SMH enhance the apprehension of all brands on a global scale. This idea was further followed in the 1990s and 2000s. Furthermore, SMH reduced the number of models produced, allowing them to improve the differentiation between the group brands. Hayek adapted brand management to the holding level in 1990. Having marketing tasks centralized made it possible to adopt a global strategy and control the strategy's implementation (Zou & Cavusgil, 2002). The main purpose of the marketing restructuring was to reposition the brands towards luxury, enhance the differentiation between the brands and invest in distribution systems. For example, the case of Blancpain exhibits how Swiss companies adapted to a new marketing strategy. In 1983, Jean-Claude Biver bought Blancpain for 18,000 CHF. He refused to switch to quartz movements, but created the picture of a traditional and technical excellent company. He claimed that the company had existed since 1735 and that it was the world's oldest watch brand. Blancpain increased sales volume from 7 million Swiss Francs in 1985 to 56 million Swiss Francs in 1991 (P.-Y. Donzé, 2011). On the other hand, Omega, a brand owned by SMH, decided to compete with Rolex but not with Longines and Rado. Intensive marketing effort was required to reposition the brand's image towards status symbols, jewelry and luxury goods for the elites who were able to purchase them. Raffaelli (2013) has argued that companies tried to identify Swiss watchmaking with luxury, beauty and craftsmanship. Between 1990 and 2008, companies with roots in the early days of mechanical watch making espoused their tradition and claimed to be luxury watch manufacturers. Swiss mechanical watchmakers focused the strategy toward affective value communication. For instance, companies tried to deliver affective values such as superior craftsmanship, history and authenticity to customers while selling mechanical watches. Unlike technological excellence, which is tangible, visible and palpable (Dion & Arnould, 2011), affective value is intangible and thus, more difficult to communicate. Eventually, the quartz crisis led to industry-wide restructuring practices towards luxury, led by the SMH (P. Donzé, 2017).

The luxury segment mainly consists of mechanical watches. However, mechanical watches only account for 28% of Swiss production volume (Federation of the Swiss Watch Industry FH, 2016). Thus, the remaining volume represents quartz watches, which are mainly of lower price segments.

4.4.7 Distinction between sales and production volume

When smartwatches first began gaining in popularity, the Swiss watch industry was the leading watchmaking country in terms of sales (Botteron et al., 2015). The global watch market was estimated to be worth 38 billion CHF, while the Swiss generated sales of 21.5 billion. This accounts for more than 50% of global watch sales. In 2015, the Swiss exported 94% of total sales (Vontobel, 2016).

Table 5 illustrates exports in million units and billion CHF per price category. The price categories refer to the official price segmentation by the Federation of the Swiss Watch Industry (Verband der Schweizer Uhrenindustrie FH, 2016). Retail prices are often three times higher than the official price category (e.g. The 200-500 CHF price category involves watches that are sold at retail prices ranging from 600- 1500 CHF). The lowest category consists of watches sold between 0 and 200 CHF and consisted of 18.6 million units in 2015. Although the revenue of 1.2 billion CHF represents the smallest number across all categories, this category possesses the highest production volume. In total, the lowest price segment, ranging from 0 to 200 CHF, involves 18.6 million exported watches and the price segment ranging from 200 to 500 CHF involves 4.5 million exported watches. Together, these categories total 23.1 million watches, representing 82% of total Swiss watch exportation. In the lowest price segment, Swatch amounts to 65% of total market share in terms of units, followed by CK watch and Mondaine with 5% each. In the segment ranging from 200 to 500 CHF, Tissot accounts for approximately 65% of total market share, followed by Certina with 10%. Exports amount to 13.8 billion CHF in the highest price category, the highest number across all price categories, while units only amount to 1.6 million pieces sold – the lowest number across all price categories. Both categories above 500 CHF amount to 87% of total exports in terms of sales. Thus, it can be stated that the Swiss watch industry is highly dependent on expensive models in terms of sales.

0-200 CHF		**200-500 CHF**		**500-3000 CHF**		**> 3000 CHF**	
Units	**CHF**	**Units**	**CHF**	**Units**	**CHF**	**Units**	**CHF**
18.6	1.2	4.5	.4	.4	.2	1.6	13.5

Table 5: In 2015, exports of Swiss watches in million units and billion CHF per price category according to Verband der Schweizer Uhrenindustrie FH (2016).

0-200 CHF		**200-500 CHF**		**500-3000 CHF**		**> 3000 CHF**	
Units	**CHF**	**Units**	**CHF**	**Units**	**CHF**	**Units**	**CHF**
18.6	1.2	4.5	.4	.4	.2	1.6	13.5

Table 6 further illustrates the distribution of sales and lists the most valuable watch brands and their corresponding price category.[17] Sales include exports and domestic sales. Rolex is clearly the top-selling brand, followed by Omega, Cartier, Patek Philippe and Longines. In 2015, the listed brands accounted for slightly more than 50% of global watch sales and for 93% of Swiss sales. The listed brands principally produce mechanical watches, whereas Longines, Tissot, TAG Heuer, Swatch, Piaget, Rado and Breitling produce both mechanical and quartz watches. The listed brands mainly compete in the most expensive price segment, whereas Longines, TAG Heuer and Rado are key players in the 500 to 3000 CHF price segment. Swatch and Tissot are the leaders in the 0 to 200 and 200 to 500 CHF price categories, respectively. The leaders have the largest market share in the corresponding price categories in terms of units. When considering the companies that owns the listed brands, it can be observed that the Swatch Group and Richemont both have 6 listed brands. Furthermore, TAG Heuer and Hublot belong to LVMH Group. The most valuable brand, Rolex, is independent as are Patek Philippe, Audemars Piguet, Chopart, Breitling and Franck Muller. In conclusion, the Swiss watch industry mainly sells luxury watches. Moreover, relatively few large watch companies comprise a substantial portion of Swiss sales.

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[17] The statistics are based on the report by Vontobel Equity Research are represent estimates.

Table 6: Top 20 Swiss brands in terms of estimated sales in billion CHF, percentage of Swiss sales and price category. The numbers are estimates of the Vontobel watch industry report (Vontobel, 2016). Analysts and researchers mostly use the Vontobel report for statistics of the watch industry (P. Donzé, 2017).

Brand	**Owner**	**Sales [billion CHF]**	**Swiss sales [%]**	**Price Category* [CHF]**
Rolex	Rolex	4.90	22.8	>3000
Omega	Swatch Group	2.06	9.6	>3000
Cartier	Richemont	2.01	9.3	>3000
Patek Philippe	Patek Philippe	1.32	6.1	>3000
Longines	Swatch Group	1.26	5.9	500-3000
Tissot	Swatch Group	1.06	4.9	200-500
Audemars Piguet	Audemars Piguet	0.805	3.7	>3000
IWC	Richemont	0.775	3.6	>3000
TAG Heuer	LVMH	0.725	3.4	500-3000
Swatch	Swatch Group	0.715	3.3	0-200
Jaeger-LeCoultre	Richemont	0.690	3.2	>3000
Breguet	Swatch Group	0.620	2.8	>3000
Chopard	Chopard	0.570	2.6	>3000
Piaget	Richemont	0.520	2.4	>3000
Vacheron Constantin	Richemont	0.500	2.3	>3000
Hublot	LVMH	0.495	2.3	>3000
Rado	Swatch Group	0.470	2.2	500-3000
Panerai	Richemont	0.440	2.0	>3000
Breitling	Breitling	0.370	1.7	>3000
Franck Muller	Franck Muller	0.285	1.3	>3000
Sum		20.15	93.4	-

*Retail prices are approximately three times higher than the official price categories.

The analysis of the Swiss watch market above illustrates that Swiss watch manufacturers have done a more than adequate job in positioning themselves within the luxury market, allowing them to charge a premium for their products (P. Donzé, 2017). However, Phau and Prendergast (2000) and Dubois and Czellar (2002) have suggested that luxury goods cannot only be defined in terms of higher prices, but must feature additional factors that are common to all luxury goods as well. The appendix defines luxury goods in more detail and presents that Swiss manufacturers of expensive watches leverage luxury factors for their products, which allows them to charge a premium. Thus far, this section has illustrated the Swiss watchmaking industry (Miles & Huberman, 1994). The remainder of this section introduces smartwatches and defines nascent smartwatch features. This study further explains how Swiss watch manufacturers have reacted to the rise of smartwatches by illustrating how Swiss watch manufacturers have reacted to the evolving smartwatch market, examining their conceptualization of nascent smartwatch features and comparing their product features with those of the key players. Finally, the article concludes and provides paths for future research.

4.5 Smartwatch

In 1982, the Pulsar NL C01 produced by Seiko could store 24 digits of information and it cost around $4,000 USD. It was one of the first smartwatches (Marshall, 2015). In 1999, the Swatch Group introduced the “Swatch Talk” that could be used as a phone. In 2004, Swatch launched another smartwatch together with Microsoft that informed the consumer about messages, weather and stocks – they called it Paparazzi. The Paparazzi used FM broadcasts as connection technology. However, a majority of smartwatches introduced during the last decades have failed to achieve any substantial level of success: Fossil Wrist PDA (2002), Sony Ericsson MBW-150 (2007), LG GD910 (2009), Samsung S9110 (2009), *inter alia*. These devices did not succeed and consequently, were removed from the market. However, when early smartwatches were on the market smartphones were not on the market. Due to the progress made within the mobile phone industry, hardware components became increasingly smaller. Furthermore, with the launch and advent of smartphones, faster mobile data networks were constructed. The smaller hardware components and the fast mobile network led to a huge adoption of mobile platforms like iOS and Android Wear. Current smartwatches use these mobile infrastructures, with Bluetooth connectivity to a user’s phone, to leverage mobile apps to the wrist (i.e. to smartwatches). In this way, current smartwatches allow a range of functionalities like counting steps, measuring heart rate or forwarding incoming push-notifications.

Firms looking to enter the market originate from distinct prior industries: computing/consumer electronics, sports and watchmaking. Moreover, a subset of startup firms are also entering the market. The companies were classified as follows: a firm that produces PCs, peripherals, smartphones or tablets was coded as computing/consumer electronics (for example Apple or Xiaomi); A firm that produces sport watches, GPS solutions for sport activities or sport wear was coded as sport; And a firm that produces watches was coded as watchmaking. Table 7[18] provides an overview of the backgrounds of firms that produce smartwatches. The list contains the main smartwatch producers according to Smartwatch Group (2015), Vontobel[19] (2016), Lamkin, (2016) and McCann and Faulkner (2016). Furthermore, the list involves all of the producers of early Swiss smartwatches. Thus, it can be seen that the emergence of smartwatches is an appropriate context in which to study the influence of prior industry affiliation on the conceptualization of nascent product features.

Moreover, I separated decisions on features from the capabilities or resources required to implement them. While a number of firms invested in developing technical capacity, which allowed

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[18] Shanda/Geak is the only producer of smartwatches with a firm background in gaming. For this reason, it was dropped from the list.

[19] The report of the bank Vontobel is one of the only comprehensive reports about the current state of the industry. The Smartwatch Group is an independent research company that analyzes the smartwatch industry and the other two sources are technical editors that have appeared as technical experts in various publications such as Forbes, BBC , the Times, the Telegraph, the Mirror and the Huffington Post.

them to launch smartwatches, firms that did not possess much technical expertise were also able to develop the same features that were incorporated into many smartwatch models. Two CEOs emphasized that between seven and eight months elapsed from ideation to the launch of their first smartwatch (“Interview: Swiss Watch CEO,” 2015; “Written Answers: Retired Watch CEO,” 2015). They also mentioned that they did not possess prior product development experience for connected devices. Additionally, various industry experts have argued that all knowledge required to produce a smartwatch with nascent smartwatch features was available within Switzerland and thus, whether Swiss manufactures would enter the smartwatch market or not was not a question of technical capability (“Interview: Expert Watch Industry Researcher,” 2015; “Interview: Watch Industry Research Experts,” 2016). In an interview, an expert researcher within the Swiss watch industry summarized the capabilities of the Swiss watch industry as follows (“Interview: Expert Watch Industry Researcher,” 2015):

“All technological capabilities in terms of developing smartwatches exist in Switzerland. We have all the microelectronics capabilities. We are among the best in the world for measuring physiological parameters. (…) Summarizing, there is no technological barrier including no barrier for successful software development.”

Swatch and Microsoft’s smartwatch from 2004, which informed users about messages, weather and stocks, had already incorporated technology that enabled it to display information from other devices. Thus, it can be seen that the conceptualization of nascent smartwatch features may be separated from firms’ technical capabilities. Technical capability should not influence a firm’s decisions regarding nascent product features. For this reason, the characteristics of the research setting are appropriate for studying the influence of prior industry affiliation on the conceptualization of nascent product features.

Table 7: Prior industry affiliation of top smartwatch firms that recently entered the smartwatch market, including all Swiss companies. The names of Swiss smartwatch firms are written in italics.

Computing/consumer electronics[20]	**Sport**	**Watchmaking**	**Startup**
Apple	Adidas	*Alpina*	Bionym
Archos	Fitbit	*Breitling*	Codoon
Asus	Garmin	Casio	Cookoo
Epson	Jawbone	Citizien	Filip Technologies
Huawei	Magellan	*de Grisogono*	Guard2me
Lenovo/Motorola	Mio Alpha	Fiyta	Limmex
LG	Nike	Fossil	Martian
Samsung	Polar	*Frédérique Constant*	Metawatch
Sony	Runtastic	*Mondaine*	Misfit
Xiaomi	Suunto	Montblanc	Mutewatch
ZTE	Tomtom	Movado	Omate
		Seiko	Pebble
		Swatch	Thalmic Labs
		TAG Heuer	Vector
		Timex	Watch
		Tissot	Wimm-Watch
		Victorinox	Withings
			Yingqu Technology

4.5.1 Nascent smartwatch features

Fast innovation, uncertainty and competition among product designs, features and technical variants are characteristics of the advent of the smartwatch market ("Interview: Expert Watch Industry Researcher," 2015; "Interview: Watch Industry Research Experts," 2016; "Written Answers: Retired Watch CEO," 2015). This is in accordance with the pattern found in prior research on technological change (Anderson & Tushman, 1990; Utterback, 1994). The evolution of smartwatches may lead to an eventual convergence on a dominant design. To trace the possible emergence of a dominant design for smartwatches, I identified a set of key smartwatch features. This approach is similar to that of Benner and Tripsas (2012). However, it is not widely used and focuses on analyzing incorporated product features while simultaneously studying an eventual convergence on a dominant design. Contrary

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[20] The listed companies in this column have smartphones in their product portfolio.

to prior research, this paper focuses on the market dimension of the process that may lead to a dominant design. On the other hand, other research has mainly discussed the technological dimension (Anderson & Tushman, 1990; Christensen et al., 1998). For example, I did not examine whether or not a smartwatch producer launched a smartwatch with an LCD, LED, OLED, PMOLED or AMOLED display; Instead, I examined whether or not a firm introduced a smartwatch with a high resolution display. Similarly, I analyzed whether or not a firm introduced a mobile platform on their smartwatches, but did not examine whether the platform was Watch OS, Android Wear, Tizen for Wearables or Pebble OS.

According to Suarez (2004), a dominant design in a certain product market exists if more than 50% of new products contain all the elements that are included within that design. However, I could not argue in favor of a specific dominant smartwatch design since there currently exist numerous variations of designs on the market and furthermore, since I do not have access to all of the data needed to accomplish such an endeavor. Nevertheless, I defined certain sets of product features that are incorporated in many nascent smartwatch models and that may possibly be part of a future dominant design. More than 250 nascent smartwatch models currently exist on the market. Key players such as Apple, Samsung, Lenovo/Motorola, LG, Pebble, Garmin, Sony, Fitbit, Withings, Polar, Asus and Xiaomi each offer several models. A subset of them – Fitbit, Xiaomi, Apple, Garmin, Samsung and Pebble – together comprise more than 70% of the total market share in terms of units[21] (Vontobel, 2016). Table 8 summarizes features of the key players' early models. Since the summary concerns the features of smartwatches offered by key players that constitute a large market share and amount to a relatively large portion of the total number of models on the market, I am confident that the data presents reasonable selection of early smartwatch features. The listed features were systematically included in the descriptions of smartwatches such as McCann and Faulkner (2016), the Smartwatch Group (2015), O'Connor, (2016), Specout (2016) and Vontobel (2016).

The goal was to include features that provide a functionality to the user. Therefore, color, material and other, similar characteristics were not considered as features. I summarized the features within the mentioned descriptions and removed features that do not provide functionality to the user. Thus, NFC was dropped as a feature since it is only a way through which to communicate between devices. A feature based on NFC would be contactless payment solutions. Moreover, I searched through the firms' websites to check for special features that may not be listed on the mentioned

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[21] This report includes estimated numbers.

webpages. In this way, I established a reasonable number of features. The features were then categorized into: habillage, communication, interaction and display. Habillage is an expression of the watch industry and represents techniques and elements related to time.

The research company Wristly, which specializes in smartwatch research, asked Apple Watch users what their primary reasons were for buying the Apple Watch (Wristly, 2016). Furthermore, Pizza, Brown, McMillan and Lampinen (2016) analyzed 1,009 smartwatch users and have found, similar to the Wristly study, that checking the time is the most frequently used Apple Watch functionality (comprising half of watch usages). They further found that Apple Watch users either check their activity progress on the Apple Watch, look at an activity notification or use the workout timer. The workout timer allows specific sports activity and monitors distance and energy consumption. Finally, users check incoming messages and manage the messages while responding to them. Both studies determined a set of widely used features that is similar to the features I chose for my examination. The following table categorizes the nascent smartwatch features.

Table 8: Summary of nascent smartwatch features. The nascent smartwatch features were incorporated into many first version smartwatches of key players within the nascent market.

Category	**Feature**
Habillage	Checking the time
	Alarm
	Timer
	Stopwatch
Fitness	Checking activity progress
	Tracking distance walked
	Tracking calories burned
	Tracking features for various sports
	Tracking on the map
	Heart rate
	Sleep monitoring
Communication	Getting informed about incoming notification
	Reading incoming notification
	Respond to notification
	Call
Interaction	Touch screen
	Voice Control
	Mobile Platform
Display	Round
	Rectangular
	High resolution display
	Analog clock display
	Digital clock display
Diverse	Special features incorporated by only one or two companies[22]

4.6 The Role of Swiss-watchmaking Affiliation on Framing Nascent Smartwatches

A large portion of Swiss sales comprise luxury watch sales. Indeed, the Swiss manufacturers are strong players within the luxury goods market. Conversely, the Apple Watch only adopts a small number of critical success factors from the luxury business model (Kapferer, 2012). A majority of the

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[22] Wireless payment, chrono flight time logs, compass, altimeter, relative humidity, air quality, temperature, weather forecast, send emergency message, count hits at beach volley and count claps

brands listed in Table 6 are positioned in the highest price segment and include Rolex, Omega, Cartier, Patek Philippe, Audermars Piguet, IWC, Jaeger-LeCoultre, Breguet, Chopard, Piaget, Vacheron Constantin, Hublot, Panerais, Breitling[23] and Franck Muller. A senior director from a clockwork manufacturer noted that such companies do not want to reach the masses, but rather niche customer segments that are willing to spend several thousand Swiss francs on a product ("Interview: Swiss Watch Director," 2015). Through email, a manager from a luxury Swiss watch manufacturer provided insight into their strategic choice regarding smartwatches ("Personal Email: Swiss Watch Manager," 2015):

> "*We are convinced that our watches will last in time. They occupy a small niche compared to the total volume of watches sold in the world today. We offer a different product (than a smartwatch), artisanal, issued in small series, distributed in selected places, appealing to very few customers in the world. We believe in the changing world there will always be a place for something rare and exceptional, such as the mechanical wonders in miniature. We develop and produce mechanical wristwatches and clocks respecting the Haute Horlogerie traditions. We continue to manufacture sophisticated watch objects and find interest among many lovers of watchmaking all over the world. We are not playing in any other segments rather than Haute Horlogerie."*

Furthermore, a retired CEO of a Swiss manufacturer of luxury watches provided the following note ("Written Answers: Retired Watch CEO," 2015):

> *"I do not believe that the top brands like Patek Philippe or Rolex will lose their strong role as providers of status symbol."*

A director of a clockwork producer similarly argued that ("Interview: Swiss Watch Director," 2015):

> *"The smartwatch is no threat for traditional mechanical watches. The market for smartwatches is completely different to the one for mechanical watches."*

The aforementioned arguments are consistent with luxury watchmaker's strategy regarding the nascent smartwatch market. Apart from Breitling, TAG Heuer and de Grisogono, no Swiss watchmaker of luxury watches has launched a smartwatch. Indeed, a majority of luxury watchmakers in Switzerland do not provide any nascent smartwatches and rely on their traditional products instead. Conversely, Tissot and Swatch are of the most successful watch brands and have announced and launched their own smartwatches with distinct features.

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[23] Breitling priced their first smartwatch at several thousand Swiss francs.

4.6.1 Preliminary conceptualization of nascent product features of Swiss smartwatches

This paragraph analyzes the initial introduction of smartwatches of Swiss watchmaking firms. Moreover, preliminary patterns are identified that may exhibit the influence of prior industry affiliation. Currently, there is high uncertainty about how products would be used and what product features would add value. For example, a retired watch CEO said in an interview that no one can answer what the value proposition of a smartwatch is (“Written Answers: Retired Watch CEO,” 2015). Thus, in such uncertain times it is necessary to understand how the Swiss have framed early smartwatch models. For this reason, the analysis includes smartwatches from Alpina, Breitling, de Grisogono, Frédérique Constant, Mondaine, Swatch, TAG Heuer, Tissot and Victorinox. This list includes all Swiss smartwatches that have been announced or launched any time before mid-2016. Early smartwatches that did not achieve market success were dropped from the list.

Almost all Swiss smartwatch manufacturers introduced round displays that do not offer high resolution and analogously display the time to the user. Accordingly, two senior executives told me that they only wanted to launch a smartwatch if it was possible to produce an attractive smartwatch that analogously displays the time (“Interview: Swiss Watch CEO,” 2015; “Interview: Swiss Watch Co-Founder,” 2015). He further emphasized that their smartwatch must remain a traditional watch. While all other early Swiss smartwatch producers provided a round display[24,] only de Grisogono and TAG Heuer incorporated a high resolution display into their first version.

Similarly, all Swiss smartwatches provide the entire set of habillage features. Habillage features are those that are related to the watchmaking industry or related to time.

Interaction features, however, were not considered to be very important by Swiss companies. Only the TAG Heuer model incorporated voice control and only TAG Heuer and de Grisogono incorporated a mobile platform into their early smartwatch model. However, a number of early Swiss smartwachtes provided a touch screen.

Furthermore, a relatively substantial number of early Swiss smartwatches offered none or only one functionality of the communication features. A watch CEO mentioned that he does not know why communication features should be incorporated into the smartwatches (“Interview: Swiss Watch Co-Founder,” 2015). He argued that receiving an email alert would not make sense since a majority of individuals receive multiple new email in an hour and they would not want to receive an alert for each of them. The Breitling and the Victorinox models only provide information about incoming notifications and thus, it is not possible to read the notification or respond to it. Only the de Grisogono model

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[24] Swatch launched two nascent smartwatches: one with a round and the other with a rectangular display.

implemented a call feature. Another watch CEO expressed that he does not understand why he should incorporate a feature for phone calls since making a phone call with a watch is unnecessarily complicated (“Interview: Swiss Watch CEO,” 2015). However, de Grisogono and TAG Heuer models do allow the user to read incoming notifications, receive notification alerts and respond to messages

Finally, a relatively substantial number of nascent Swiss smartwatches implemented fitness features, except for the Breitling model. However, none of the Swiss smartwatches offered features for tracking various sports and only Tissot and Victorinox offer tracking distances on maps. Furthermore, the de Grisogono smartwatch is the only one that offers a heart-rate measurement function, while Alpina, de Grisogono, Frédérique Constant and Mondaine offer sleep monitoring.

To summarize, a majority of Swiss watchmaking firms that entered the nascent smartwatch market appear to perceive a smartwatch as a device that is used in a manner similar to a traditional watch. Indeed, the majority of manufacturers with prior industry affiliation in watchmaking conceptualized round displays, not high resolution and analog clock displays. Such conceptualization is similar to the conceptualization of their products in the watchmaking industry. Only touch screen functionality was incorporated by manufacturers, whereas the other interaction features were only incorporated by one or two firms. All of the functionalities related to time were conceptualized into all of the nascent Swiss smartwatches. A majority of these watches do not offer any communication features or only provide notification alerts, although many incorporated at least a subset of the fitness functionality. None of them, however, conceptualized the entire set of fitness features within their first version.

Table 9: Swiss smartwatch producers and their conceptualization of nascent product features.

Feature	**Alpina**	**Breitling**	**de Grisogono**	**Frédérique Constant**	**Mondaine**	**Swatch**	**TAG Heuer**	**Tissot**	**Victorinox**	**Firms with feat**
Round display	x	x	x	x	x	x	x	x	x	9
Rectangular display						x				1
High resolution display			x				x			2
Analog clock display	x	x		x	x	x		x	x	7
Digital clock display			x			x	x			3
Touch screen			x			x	x	x		4
Voice control							x			1
Mobile platform			x				x			2
Checking the time	x	x	x	x	x	x	x	x	x	9
Alarm	x	x	x	x	x	x	x	x	x	9
Timer	x	x	x	x	x	x	x	x	x	9
Stopwatch	x	x	x	x	x	x	x	x	x	9
Reading incoming notifications			x				x			2
Getting notification alert		x	x				x		x	4
Respond to message			x				x			2
Call			x							1
Checking activity progress (steps)	x		x	x	x	x	x		x	8
Tracking distance	x		x	x	x	x	x	x	x	8
Counting calories	x		x	x	x	x	x		x	7
Various sports tracking features						x				1
Tracking on the map								x	x	2
Heart rate			x							1
Sleep monitoring	x		x	x	x					4

4.6.2 Preliminary conceptualization of nascent product features of key players within the nascent smartwatch market

Contrary to the Swiss smartwatches, the key players in the nascent product market primarily offer rectangular displays, use high resolution displays and conceive the time digitally. Only one Withings model provides hands for their early smartwatch. However, it is important to note that key players such as Pebble, LG, Samsung announced that their newer smartwatch models will have a round display.

With regard to the interaction features, a majority of smartwatch models have a touchscreen and offer a mobile platform. According to their prior industry affiliation, almost all of the computer/consumer electronic firms with smartphones in their product catalogue provide a mobile platform. Pebble also offers a mobile platform. Similarly, with regard to the voice control feature (apart from Pebble) only companies with smartphones in their product portfolio incorporated this feature as well.

The features related to time are also offered by relatively many companies, but only four offer the entire set of habillage functionalities.

Both receiving notification alerts and reading incoming notifications were incorporated by firms with prior computing/consumer electronics affiliation. Interestingly, only companies with prior experience in this industry offer additional communication features within their early models, such as making a call and responding to notifications. Nevertheless, the analog Withings model does not offer any notification features.

Similar to Swiss smartwatches, a majority of the models offer many of the fitness features. However, the sports companies exclusively provide the entire set of fitness features. Companies with a different prior industry affiliation offer a subset of the fitness features, whereas heart rate and sleep monitoring are features that are offered by almost all manufacturers.

In summary, all Swiss smartwatches offer the entire set of the habillage features, which involve being able to check the time, set an alarm and use a timer and stopwatch. However, many other producers also offer at least a subset of these features. Similarly, a majority of Swiss smartwatch makers have a round display, do not provide a high resolution display and conceive the time analogously. Conversely, smartwatches of key players have a rectangular display, high resolution display and conceive the time digitally. Moreover, voice control and mobile platform features were only incorporated by one or two Swiss producers, whereas touch screen functionality was incorporated by a number of Swiss smartwatch producers. A mobile platform and voice control were primarily incorporated by firms that have a background in the computing/consumer electronics industry.

Only relatively few Swiss manufacturers provide notification features, whereas only de Grisogono incorporated the entire set of communication features. Similarly, companies with a different industry background than computing/consumer electronics do not offer the entire set of communication features. However, the features “Reading Incoming Notifications” and “Getting Notification Alerts” are widely used by many of the key players, but not by many Swiss firms.

Fitness features such as checking activity progress, tracking distance and counting calories were incorporated by both key players and Swiss firms. Additional fitness features such as “various sports tracking features,” “tracking on the map” and “heart rate” are not covered by many Swiss firms. While four out of nine Swiss manufacturers offer the sleep monitoring feature, the entire subset of fitness features is only provided by key players with prior industry affiliation in sports. Similar to Swiss companies, only a select number of key players with a different backgrounds provide the “tracking on the map” and “heart rate” features.

Table 10: Key players in the smartwatch market and their corresponding conceptualization of the nascent smartwatch market

Prior industry affiliation	Computing/ consumer electronics							Sport			Startup		Firms with feat.
	LG	Samsung	Sony	Xiaomi	Motorola/Lenovo	Apple	Asus	Garmin	Fitbit	Polar	Pebble	Withings	
Round display	x				x							x	3
Rectangular display	x	x	x	x			x		x	x	x	x	9
High resolution display	x	x	x		x	x	x	x		x		x	9
Analog clock display												x	1
Digital clock display	x	x	x	x	x	x	x	x	x	x	x	x	12
Touch screen		x	x	x	x	x	x	x	x	x		x	10
Voice control	x	x			x	x					x		5
Mobile platform	x	x	x		x	x	x						7
Checking the time	x	x	x	x	x	x	x	x	x	x	x	x	12
Alarm	x	x	x	x	x	x		x	x	x	x	x	11
Timer	x				x	x			x	x	x		6
Stopwatch	x	x	x	x	x	x		x	x				8
Reading incoming notifications	x	x	x		x	x	x	x		x	x		9
Getting notification alert	x	x	x	x	x	x	x	x	x	x	x		11
Respond to message	x	x	x			x							4
Call		x	x			x							3
Checking activity progress	x	x	x	x	x	x	x	x	x	x	x	x	11
Tracking distance	x	x	x	x	x	x	x	x	x	x	x	x	12
Counting calories	x	x	x		x	x	x	x	x	x	x	x	11
Various sports tracking features			x					x	x	x	x		5
Tracking on the map		x	x					x	x	x			5
Heart rate				x	x	x	x	x	x	x		x	8
Sleep monitoring	x	x		x		x		x	x	x	x	x	9

4.7 Discussion

A new product market is often characterized by high uncertainty, especially with regard to product characteristics that will eventually converge on a dominant design. Indeed, firms lack an adequate understanding of customer preferences since they have no prior experience within the nascent market. For this reason, they experiment with various product designs and develop initial products based on their assumptions. Thus far, research has indicated that high technical differences appear during the early phases of technological development. In later phases of technical development research has documented a convergence on a dominant design. However, research has not examined differences in product features within a nascent product market and how these differences may also influence the convergence on a dominant design.

Thus, the present research examined these issues through an exploratory research of the emergence of smartwatches: In this endeavor, it examined the impact of a firm's prior industry experience on the conceptualization of product features during the early phase of a nascent product market. The analysis revealed that Swiss watchmaking firms have mainly framed a smartwatch as an analog watch substitute, while computing/consumer electronic firms have framed a smartwatch more as a computing device and sports companies have framed it as a device with comprehensive fitness features. Thus it can be seen that firms from the same prior industry conceptualize nascent product features similarly. We see that firm heterogeneity is an important factor for shaping the initial conceptualizations of product features. In particular, firms from the same prior industry have a common understanding of initial product features. Consequently, prior industry affiliation is an important source of initial heterogeneity for a nascent product market in terms of nascent product features. The exploratory results indicate that a firm's choice of initial product features is influenced by common worldviews and mindsets. Indeed, socio-cognitive factors influence managers who try to make sense of confusing and conflicting signals (Weick, 1990). Beliefs from a firm's previous industry experiences further influence managerial decisions (Tripsas & Gavetti, 2000). Thus, the results suggest that firms that analyze, interpret and conceptualize products for a nascent product market are influenced by their prior industry experience.

This paper contributes to the extant research in several ways. The conceptualization of early smartwatch features should not have been influenced by a firm's underlying technical knowledge and capability ("Interview: Expert Watch Industry Researcher," 2015). In general, Swiss firms could select what features they wanted to incorporate into their smartwatches. However, a firm's technical capabilities and resources are still important for understanding why firms behave differently in this respect. This research has revealed that managerial beliefs and understandings are associated with industry experience. This association may be regarded as an additional key factor in how firms approach new product markets. Thus, research should examine capabilities, resources and shared beliefs, while simultaneously examining firm behavior. Similarly, managers should focus on competitors' capabilities and resources and additionally, consider assumptions and beliefs that competitors bring into a nascent product market.

A new product market is characterized by fleeting product characteristics, market boundaries and user needs (Aldrich & Fiol, 1994; Lounsbury, Ventresca & Hirsch, 2003; Santos & Eisenhardt, 2009). The emerging industry involves players from various prior industries and can be regarded as a converging industry. This research adds to the industry convergence literature by examining initial product features within a converging industry that were introduced by firms with distinct prior industry experience.

This paper also contributes to the research on industry evolution. The convergence on a dominant design is a twofold process that incorporates both a technological and market variable (Clark, 1985). The market variable of the process concerns the initial variance in product features and has not received much attention within research. Prior research has mainly focused on examining the technologies that were incorporated into dominant designs and how the selection of these technologies influenced the emergence of a dominant design. Perceptions of what a smartwatch is used for and therefore, what a potential customer values, converged on an early set of nascent smartwatch features. The early set of features covers a range of variations and use cases that are associated with prior industry conceptualizations as well as with a new product type. This study examined competing features and perceptions of what firms within the nascent smartwatch market thought customers would value. While the early conceptualization already defined a set of smartwatch features that may be regarded as a set of standard features of an early product design, the initial product design involved features and use cases that are associated with the distinct prior industry affiliations. Indeed, a specific set of features related to a certain prior industry affiliation was mainly incorporated by firms from a given prior industry. Firms with prior Swiss watchmaking and sport affiliation incorporated all features related to time and sports, respectively.

4.7.1 Limitations

The chosen research setting made it possible to study the introduction of nascent product features. The technical capabilities needed to introduce a broader range of features existed in Switzerland. However, analyzing patent data would have allowed to control for technological capabilities, which would have made it possible to examine whether or not technological capabilities have an effect on the introduction of nascent product features. Moreover, there may be firms with greater bargaining power over their supply chain. While this also may have affected the access to particular features (Benner & Tripsas, 2012), this research did not examine the setting of suppliers and partners nor the possible influence of the buyer's power.

Furthermore, it is necessary to ascertain whether firms seek to serve specific customer niches or take advantage of specific distribution channels. This may influence their choices of nascent product features Therefore, marketing strategies may have an impact on the firm's decisions regarding the conceptualization of nascent product features. Nevertheless, it is important to note that a number of the set of fitness features was incorporated into the smartwatches by almost all of the smartwatch producers. Moreover, almost all of the firms conceptualized at least few features for each of category: habillage, fitness, communication, interaction and display. This study did not control for how a firm's brand or marketing strategy may have influenced the conceptualization of nascent product features. However, while this and all alternative explanations cannot be explicitly controlled for, the results indicate that it is likely that the influence of shared beliefs and imitation arising from prior industry experience play an important role in the conceptualization of nascent product features.

4.7.2 Future research

There are also a number of recommendations for future research that must be taken into consideration. Since this paper only analyzed the nascent market for smartwatches, future research should similarly address a more advanced smartwatch market and examine how a dominant design emerges while considering both the market and the technological dimensions of the convergence on a dominant design.

Within the smartwatch market, start-up firms also play a role. While many entered the market, only few have become major players. Indeed, the early smartwatch market is dominated by established firms. Since many have entered, however, entrepreneurial opportunity exists. Thus, this setting of convergence of multiple industries (including startup firms) should be discussed further. Questions about the importance of distribution systems for success may also be examined (Tripsas, 1997). Conversely, within the digital camera industry only a small number of startups entered and do not play a major role. Questions about the importance of established distribution centers should be included within future research as distribution centers do not seem to play an important role within the smartwatch market. Moreover, in the case of startups, it may be interesting to examine how backgrounds of founders influence how they conceptualize a new industry and choose their product characteristics.

While this study focused exclusively on a specific product market that is part of a network, research about newly emerging product markets that ultimately shape industry boundaries has examined boundary decisions in isolation and has primarily discussed industries within well-structured environments (Santos & Eisenhardt, 2009). A smartwatch does not compete and operate in isolation, but is a member of a larger network that involves, for example, smartphones, tablets and software. Such a setting can be regarded as an industry architecture that is an important factor of new industry emergence (Jacobides, Knudsen & Augier, 2006). Thus, a possible area for future research would be to study how a firm’s prior industry affiliation influences the preferred industry architecture. The emergence of such an industry that is characterized by evolving modular boundaries is an important aspect of new industry emergence.

Finally, future research should consider how a firm’s background influences firm performance. While scholars have discussed how the timing and the adoption of a dominant design affects the survival rate of firms (Suarez et al., 2014; Suarez & Utterback, 1995), such research has again focused almost entirely on the technological aspect of a dominant design. Thus, future scholars may discuss how the adoption of features and the timing of this adoption affect firm performance.

Chapter 5 Overall Conclusion

The overall purpose of this PhD thesis is to explore the processes and mechanisms of the product life-cycle of technological development (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). First, the research provides a better understanding of the dynamics during the era of incremental change. Second, it explains the interrelationships between the three stages of the product life-cycle. In particular, it discusses the shift away from the era of incremental change towards the ferment stage. Third, it clarifies how a dominant design may emerge out of the ferment stage of dominant designs.

Summarizing and comparing essay one and two, several patterns became apparent. Intensive collaboration practices between manufacturers and suppliers in new product development during the era of incremental change appear to facilitate innovations that cannot be managed within an established product architecture. The collaboration and knowledge sharing intensity triggers technological discontinuities that change the established dominant design and shifts the product life-cycle away from the era of incremental change towards the early stage of ferment. Essay one revealed that the shift away from the phase of stability and well defined interfaces and components also has implications for collaboration and knowledge management practices. After this shift, firms must interact with various old and new actors to closely follow technological developments that occur beyond the firm's boundaries. Furthermore, they must adapt their standard operating procedures to design and develop new products. The collaborative and integrative organizational and knowledge management practices valuable for the era of incremental change become, to some extent, obsolete after the shift. Firms no longer have knowledge of component specifications and thus, are unable to adequately specify their component needs and requirements to their outside suppliers. Similar to the conceptual paper, the quantitative study reveals that relatively intense collaboration practices may lead to technological discontinuities that have to be captured within a new product architecture (Bozdogan et al., 1998; Brusoni et al., 2001; Henke & Zhang, 2010). The new architecture is characterized by new components and interactions between those components. Furthermore, it appears that technological discontinuities (novelties) need to be captured in a new architecture and that such discontinuities shift the technological life-cycle away from the era of incremental change towards the era of ferment. Additionally, essay two explains that firms cannot create breakthrough innovations that involve new technologies and serve new markets if they only improve existing products based on the established product architecture. New product introductions based on established product architectures maintain the product life-cycle of technological evolution in the stage of incremental change. Thus, both essay one and two indicate that a technological discontinuity may emerge during the era of incremental change due to relatively intensive collaboration and knowledge sharing practices with suppliers in new product development. The technological discontinuities disrupt the era of incremental change and subsequently, create a new technological cycle that shifts away from the established dominant design towards the era of ferment.

The summarized conclusions of essay and two provide important insight into the current setting of converging industries (Brusoni et al., 2009). Converging industries are characterized by technologies blurring industry borders. Firms that are affected by technology and come from previously distinct fields incorporate such perceived new technologies into their products. Essay one and two further explain that in order to incorporate new technologies into a new product, firms appear to change the established dominant design while shifting away from the era of incremental change. Technologies that originate in previously distinct fields are incorporated into a new product architecture during the era of ferment (Fleisch, 2016; Henderson & Clark, 1990). Thus, firms affected by industry convergence should be prepared to shift from the era of incremental change to the era of ferment, which is characterized by high market and technological uncertainty. To incorporate previously distinct technologies into new products, firms begin involving distinct technologies beyond traditional new product development boundaries early on and interact with various actors beyond their actual new product development practices.

Finally, essay three discussed the market of nascent smartwatches, which is characterized by firm heterogeneity. Moreover, uncertainty provides interesting insight into the mechanisms and processes of industry evolution. Within a nascent product market, firms lack a better understanding of customer preferences since they do not have prior experience within the nascent product market. Thus, they experiment with various product designs and develop initial products based on their assumptions, which are rooted in the industry in which they previously conducted business. The qualitative study further illustrated that firms from the same prior industry appear to have similar assumptions about a nascent market and consequently, they assume similar customer needs and conceptualize their products in a similar way. The early conceptualization of nascent product features defines a set of nascent features that can be regarded as a set of standard features of the early product design. The initial product design involves sets of features and use cases that are associated with the distinct prior industry affiliations. A specific set of features related to a certain prior industry is mainly incorporated by firms from that prior industry. Thus, it can be observed that the conceptualization of nascent product features and firm heterogeneity may play an important role in the eventual convergence on a potential dominant design. Overall, this improves our understanding as to how technology evolves, and more broadly, how industries evolve.

5.1 Future Development

The results also helped determine a number of suggestions for future research. Future research should empirically explore how close cross-organizational integration practices with suppliers in new product development trigger a shift away from the era of incremental change and whether or not a kind of second, loosely coupled network that looks beyond the firm’s boundaries helps established firms manage the shift away from the era of incremental change towards the stage of ferment (Henderson & Clark, 1990).

Research about newly emerging product markets that ultimately shape industry boundaries has examined boundary decisions in isolation and primarily discusses industries within well-structured environments (Santos & Eisenhardt, 2009). Similarly, the third essay focused exclusively on a specific product market. However, a smartwatch is a member of a larger network that includes smartphones, tablets, software and personal computers. Such a setting can be regarded as an industry architecture that is an important factor of new industry emergence (Jacobides et al., 2006). A possible area for future research would be to study how a firm's prior industry affiliation influences the preferred industry architecture.

Moreover, by tracking how alliances and networks of organizations from distinct industries trigger technological discontinuities, which in turn shifts the product life-cycle away from the era of incremental change, scholars may be able to better explain processes of industry convergence (Lee, 2007).

Essay one and two indicate that suppliers are an important source for innovations as well as for technological discontinuities. A possible path for future research would be to examine what important criteria of supplier selection (supplier capability, technological uncertainty, modularity, geographical proximity and trust) are critical for helping suppliers innovate and consequently, shift the product life-cycle of technological evolution away from the era of incremental change towards the stage of ferment (Rosell & Lakemond, 2011).

Finally, scholars have discussed how the timing and adoption of a dominant design affects firms' survival rate (Suarez et al., 2014; Suarez & Utterback, 1995). Such research has mainly examined the technological aspect of a dominant design. Thus, scholars may discuss how the adoption of features and the timing of this adoption affect firm performance within a nascent product market.

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Curriculum Vitae

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WORK HISTORY

09/ 2013 – 02/ 2017	PHD AT THE CHAIR OF CORPORATE STRATEGY AND INNOVATION AT THE COLLEGE OF MANAGEMENT OF TECHNOLOGY AT EPFL IN LAUSANNE

11/2012 – PRESENT

BUSINESS CONSULTANT/ EXPERT BUSINESS ANALYST AT ZÜHLKE

FEW EXAMPLES OF PROJECTS:

- EVALUATION OF THE INNOVATION MANAGEMENT OF A RELATIVE LARGE ENERGY SUPPLY COMPANY
  - CHOOSING THE RIGHT METHODOLOGY FOR THE EVALUATION
  - CREATING A HIGHLY-QUALIFIED ASSESSMENT OF THE INNOVATION MANAGEMENT
  - CREATING AN ASSESSMENT REPORT AND DISCUSSING THE FINDINGS WITH THE CUSTOMER
- IMPROVING THE IT STRATEGY OF A CANTONAL ENERGY SUPPLY COMPANY:
  - DEFINITION OF AN IT VISION
  - ALIGNING IT STRATEGY TO CORPORATE STRATEGY
  - EXAMINING FORCES INFLUENCING THE IT STRATEGY
  - DEFINITION OF A SPECIFIC ACTION PLAN WITHIN IT IN ORDER THAT THE CORPORATE STRATEGY MAY BE IMPLEMENTED
- IMPLEMENTING AN INTEGRATIVE FOOTBALL AND EVENT MANAGEMENT SYSTEM FOR A LARGE FOOTBALL SUPPLIER:
  - CUSTOMER WANTS TO INTEGRATE SEVERAL SYSTEMS INTO ONE NEW APPLICATION
  - MAINLY OPERATIVE LEAD OF THE PROJECT MANAGEMENT OFFICE AND BUSINESS PROCESS ENGINEERING

    -
- Business model innovation in different industries:
    - Definition of actual business models for various industries in Switzerland, evaluation of the competitive advantage and development of new business models of typical companies within a specific industry

02/2012 – 10/2012

Master Thesis at Rivella AG
Economic and ecological analysis of the logistics network at Rivella AG including potentials for improvements

03/ 2011 – 07/ 2011

Internship at SWISS International Air Lines Ltd.
Department: Corporate Procurement Development Services

- Business analysis and project office for the reorganization of the uniform supply chain
- Organization and administration of the procurement board meetings
- Independent project to implement a software tool for the mobile phone administration

09/ 2008 – 06/ 2009

Private Tutor in Mathematics

2001 – 2006

Temporary summer employments at Grässlin KBS GmbH in St. Antoni

- Quality Management

Education

09/ 2013 – 03/ 2017

PhD at the Chair of Corporate Strategy and Innovation at the College of Management of Technology at EPFL in Lausanne (Professor Christopher L. Tucci)

Title: Diving into the dynamics of product evolution: Analyzing technological discontinuities during the era of incremental change and cognitive convergence on a dominant design

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09/ 2009 – 10/ 2012

Master of Science ETH in Management, Technology and Economics at ETH Zurich

- 08/ 2011 – 12/ 2011 Exchange at National University of Singapore (NUS) in Singapore, 08/ 2011 – 12/ 2011

10/ 2006 – 09/ 2010 Bachelor of Science ETH in Environmental Engineering at ETH Zurich

- Bachelor Thesis: Impact of climate change on urban runoff systems
- Study focus on air pollution control

08/ 2001 – 07/ 2005 A Levels at Kollegium St. Michael in Freiburg, CH

- Focus: Mathematics and Italian

08/ 1998 – 07/ 2001 Secondary School in Tafers, Freiburg CH

Selective Services

09/ 2010 – 02/ 2011	Civilian service in a day care center for kids in Zurich
07/ 2005 – 12/ 2005	Artillery military training school in Frauenfeld

Languages

German	Mother Tongue
English	Oral and written: fluent Global Village English Centre in Vancouver, 03/2006 – 06/ 2006, Cambridge Certificate in Advanced English. PhD in English
French	Oral: fluent, written: advanced
Italian	Oral: basics, written: basics

Qualifications/ Courses

Windows and Mac	Very good knowledge
MS Office incl. Visio	Very good knowledge
Matlab:	Good knowledge (Bachelor Thesis)
SQL and R:	Good
Business Engineering:	OMG in BPM, IREB Certified Professional for Requirements Engineering (CPRE), Course in agile business analysis
Enterprise Architect:	Good knowledge
Jira:	Basic knowledge
Lean – Kaizen – Six Sigma	EPFL Certificate
Personal development:	Courses in conflict management and communication with challenging partners

Further Interests

Hobbies: Biking, Cooking, Cross-Country Skiing, Hiking, Jogging, Music, Photography, Reading, Skiing, Culture.

Former Photographer at the Institute of History and Theory of Architecture (gta) at ETH Zurich

Former leader: Jungwacht und Blauring St. Antoni (5 years) and Youth Skiing Camp Schwarzsee (4 years)