# Understanding platform-based product development : a competency-based perspective



*DOI:*
10.6100/IR673035

*Document status and date:*
Published: 01/01/2010

*Document Version:*
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

# UNDERSTANDING PLATFORM-BASED PRODUCT DEVELOPMENT: A COMPETENCY-BASED PERSPECTIVE

**WANG QI**

NATIONAL UNIVERSITY OF SINGAPORE

&

EINDHOVEN UNIVERSITY OF TECHNOLOGY

**2008**

# UNDERSTANDING PLATFORM-BASED PRODUCT DEVELOPMENT: A COMPETENCY-BASED PERSPECTIVE

WANG QI

A DISSERTATION SUBMITTED

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

NATIONAL UNIVERSITY OF SINGAPORE

&

EINDHOVEN UNIVERSITY OF TECHNOLOGY

2008

Understanding Platform-based Product Development: A Competency-based Perspective

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus, prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op maandag 17 mei 2010 om 10.00 uur

door

Wang Qi

geboren te Shanghai, China

Dit proefschrift is goedgekeurd door de promotoren:

prof.dr. A.C. Brombacher
en
prof.dr. J.I.M. Halman

Copromotor:
dr. K.H. Chai



A catalogue record is available from the Eindhoven University of Technology Library
ISBN: 978-90-386-2219-4

Keywords: Platform; Product development; Competency; Success factor; Technological turbulence; Product family

Printed by: University Printing Office, Eindhoven

# ACKNOWLEDGEMENTS

This dissertation would have never been completed successfully without the help from those who have supported me throughout the journey of my doctoral studies, including supervisors, colleagues, friends and of course my family. I would like to take this opportunity to express my appreciation to all of them.

Firstly, I would like to thank my three supervisors at NUS and TU/e. Their continuous support and encouragement in many ways help me finish this dissertation. In particular, I would like to thank Dr. Chai at NUS. It was Dr. Chai who led me into this research field and guided me throughout the whole period of my Ph.D. study. His enthusiasm, patience, and support have kept me working on the right track with a high spirit. His comments and recommendations of my reports are always timely and thoughtful. At TU/e, I would like to thank Professor Brombacher and Professor Halman. Although they had a tight schedule, they always managed to find time for me every week when I was at TU/e from 2005 to 2006, and used other communication media (video conference, telephone and of course e-mail) when I was in Singapore. As a result, we had lots of efficient and fruitful discussions and many of which have been incorporated in this dissertation. Their valuable comments have greatly helped me to improve this work. Working with my three supervisors is an exceptional experience for me, and I believe this experience will definitely benefit me for the whole life. In addition, I also want to express my deep appreciation to Professor Michael Song especially. Without his great help, my survey could not have been conducted successfully in the United States. His comments and suggestions were critical but very useful, which helped me overcome some theoretical difficulties. Thank you, Professor Song.

I am also very grateful to my colleagues in the ISE Department of NUS. They include Awie, Zhou Peng, Lin Jun, Xiao Yang, Xin Yan, Hong Ling, Yu Feng, Ren Yu, Shabnam, Joice, Mei Cheng, Virginia, Ayon and others. I benefited a lot through discussion with them about my research methodology, research gaps, and so on.

My special thanks also go to the staff in the QRE department of TU/e for their kind help, particularly to Peter Sonnemans, Simon Minderhoud and Lu Yuan for their contribution and collaboration in this project, from whom I have learnt not only knowledge but also skills in research, which enriches this research from practical point of view. Such appreciation also needs to be conveyed to Jan Rouvroye and Hanneke Driessen, who helped me adapt to the life and culture in the Netherlands.

Without the support from my family, this thesis would have been impossible. Lastly, I want to thank my parents for their patience, support and encouragement, which actually helped me overcome all the difficulties faced throughout the course of doctorial studies.

Wang Qi

Feb 2008

# TABLE OF CONTENTS

# SUMMARY

In recent years, the competition in product development and innovation has intensified through increased demand heterogeneity and shorter product life cycles. An increasingly popular strategy to meet the mentioned challenges is the use of a platform-based approach to create a successful product family for the purpose of increasing variety, shortening lead-times and reducing costs. However, unlike the well-published benefits of platform-based product development, a clear gap in literature still exists when it comes to understanding how to implement and manage product families and their successive platforms. We do not know enough about the key attributes of platform-based product development which can contribute to a competitive advantage, which in turn leads to the success of a platform. In addition, the impacts of a turbulent environment on platform-based product development remain largely unknown. Given these limitations, our research is directed at building a framework to better manage platform-based product development from a competency perspective and specifically, we want to addresses the following research question:

How can firms improve their platform-based product development performance, from a competency-based perspective?

Based on existing literature and the interviews in four leading technology-driven companies, we propose the concept of product platform competency, and identify its antecedents. We hypothesize that such competency directly affects the performance of platform-based product development. However, these effects are moderated by the turbulence of the environment.

To test these hypotheses, a large-scale survey is conducted in the United States. After analyzing the data by the means of structural equation modeling using LISREL 8.7 and hierarchical multiple regression using SPSS 15.0, we find sufficient empirical evidences to support most of the hypotheses. The results lend support to the concept of product platform competency which comprises reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products. Our results show that a formalized development process, design knowledge dissemination across platform-based products, continuity of platform-based product development team and existence of a champion in platform-based product development significantly affect product platform competency. Additionally, our findings further suggest that in a high technologically turbulent environment, some of these factors have even greater impact on product platform competency. Based on the results of this study, product platform competency can be considered as the underlying cause of high performance of platform-based product development. Therefore, managers are strongly encouraged to apply the aforementioned four management practices to improve their product platform competency, especially in a high technologically turbulent environment. This in turn should lead to reduction in the development cost and time.

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1 Introduction

## 1.1 Research background

In recent years, the competition in product development and innovation has intensified through increased demand heterogeneity and shorter product life cycles. Companies are trying to introduce new products in shorter intervals with higher levels of product variety to gain more profit (Wheelwright and Clark, 1992), despite the constraints on time, funds, required quality and other condensed resources (Leithhead, 2000; Ward and Chapman, 1991). Some approaches have been proposed in new product development to accelerate the process, decrease the cost and improve the product quality, such as concurrent engineering and total quality management (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992; Smith and Reinersten, 1998; Cristiano et al., 2000; Bhuiyan, 2001; Fiore, 2005). In order to meet the mentioned challenges, in addition to the use of process management strategies, an increasingly popular strategy in product architecture innovation is the modularization of products and the use of a platform-based approach to create a successful product family. Unlike the previous practice of designing one product at a time, many companies have started utilizing the platform approach to develop and produce product families for the purposes of increasing variety, improving customer satisfaction, shortening lead-times and reducing costs (Simpson et al, 2006). This approach has been widely advocated in literature (see e.g. Veenstra et al, 2006; Jones 2003; Krishnan and Gupta, 2001; Meyer and Lehnerd, 1997; Meyer et al, 1997) as an option to create desirable variety at a cost acceptable to the consumers. A widely known example is Sony's great success in developing more than 160 Walkman models from 5 product platforms between 1980 and 1990. Such practice allowed Sony to dominate the personal portable stereo market for over a decade and remain the leader both technically and commercially (Sanderson and Uzumeri, 1997). In the computer industries, Apple sold a total of 2 million computers of seven different models based on the Macintosh platform first released in 1984 (McGrath, 2001).

While the benefits of modular and platform-based product development are well known (Mikkola and Gassmann, 2003), a clear gap in literature still exists when it comes to understanding how to implement and manage product families and their successive platforms (Halman et al., 2003; Jones, 2003). According to Meyer (1997, pp. 17), "product platforms must be managed" and "robust product platforms do not appear by accident". As shown in Hauser's (2001) 5-year study at one high technology firm, if the platform approach is not applied properly, it does not improve profitability. Similarly, Krishnan and Gupta (2001) also report that high design costs and low product quality can happen when using the platform approach. Therefore, in order to employ the product platform effectively and achieve the desired performance, one needs to know the critical organizational factors and practices which underpin successful platform-based product development. According to Mills et al. (2002) and Kleinschmidt et al. (2007), one sustainable way to improve performance is to improve the underlying competency to achieve a competitive advantage. Therefore, it may be fruitful to view platform-based product development from a competency-based perspective.

Moreover, a constantly changing environment is likely to bring additional challenges to platform development. According to D'Aveni (1994) and Dickson (1992), teams in new product development who are exposed to rapid technology changes have difficulties in mastering new technologies. Therefore, such technological turbulence may influence the relationship between product development activities and its performance (Swan et al. 2005; MacCormack and Verganti, 2003; Souder and Song, 1997). As such, the influence of different levels of technologically turbulent environments should also be considered in the context of platform-based product development.

## 1.2 Research objectives

Examination of the existent literature reveals several drawbacks that limit our understanding of platform-based product development. Firstly, what can help companies to win a sustainable competitive advantage with their platforms? There are some studies in the context of platform-based products, in which the benefits are presented as well as some characteristics of platform-based product development are illustrated (i.e. Krishnan and Gupta, 2001; Tatikonda, 1999; Kim et al., 2005; Jones, 2003). However we are still not very clear about the key attributes embodied with platform-based product development that may help companies win a sustainable competitive advantage with their platforms. Secondly, while researchers have identified most of the successful management practices and success factors in new product development, either at the single project (product) level or at the firm level (Johne and Snelson, 1988; Ernst, 2002)，our understanding on potential successful management practices and success factors in the context of the development of product families and their successive platforms (Halman et al., 2003; Jones, 2003) remains limited. Although success factors and management strategies have been summarized in previous studies, for the singular product management approach, they may not be appropriate in the context of platform-based product development (Tatikonda, 1999). There are no clear answers yet regarding the successful management practices and success factors explicitly applicable in the context of firms' platform-based product development that may improve platform competency. Therefore, in order to provide more insights specifically for platform-based product development in the companies, there is more to be learned and validated with large scale empirical research. In addition, the effects of certain management practices in platform-based product development could also be impacted by turbulent environments (Bstieler, 2005). Unfortunately, all of these issues have not been explored sufficiently by previous studies, further research will therefore be necessary.

Given these limitations of existing knowledge, in order to reduce the research gaps, our research is directed at building a framework on managing platform-based product development from a platform competency perspective. With respect to the major limitations alluded earlier, i.e. key attributes for a sustainable competitive advantage, corresponding successful management practices and success factors explicitly applicable in the context of firms' platform-based product development that improve platform competency and the impact of turbulent environments, there is more to be learned and validated with empirical research to provide more insights and industry applications. Accordingly, the aim of this study is threefold: firstly, to identify and understand what constitutes a product platform competency and examine the impact of such competency on platform performance; secondly, to identify the underlying factors that enhance the product platform competency; and thirdly, to examine the role of a turbulent environment in the context of platform-based product development.

## 1.3 Structure of the dissertation

The dissertation consists of six chapters. A brief description of each chapter is listed as follows:

Chapter 2 – Literature Review: In this chapter, we first focus on review of the relevant literature on modular product development and platform-based product development which we introduced in Chapter 1. The competency-based theory is examined next. An extensive literature review of success factors in new product development is further performed. This review is followed by a discussion of the limitations of previous studies. The research questions are brought forward based on the result of the literature review.

Chapter 3 – Hypotheses development: Based on the existing literature and our field studies in four leading technology-driven companies, three sets of hypotheses are proposed for empirical testing in this chapter. They are presented in the following sequence: product platform competency and its impact on platform technical performance; antecedents of product platform competency—management practices in platform-based product development; and moderating effects of technologically turbulent environment in platform-based product development.

Chapter 4 – Survey instrument development and implementation: A large-scale survey is chosen as the research methodology to validate the hypotheses we developed in Chapter 3 and the unit of analysis is the derivative products based on one common platform. In this chapter we first explain how we operationalize theoretical constructs with measurable items, and how these items are adapted from the mainstream literature or from our field studies for our research objectives. Secondly, we elaborate on the process of our questionnaire design. Lastly, we describe the sample populations we chose in our study and the procedures we took to conduct the survey, which includes pre-survey and final survey implementation.

Chapter 5 – Data analysis and Results: Following the procedures elaborated in Chapter 4, a total sample size of 242 firms with complete data is used in our data analysis. Firstly, a descriptive analysis is conducted for a better understanding of the profiles of sampling populations, as well as to assess the validity of the data set. The measurement model is then assessed through both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). After checking the validity of the measurement model, we next test the hypotheses regarding the direct effects in the structural model through structural equation modeling (SEM) using LISREL 8.7. Finally, the hypotheses regarding the moderating effect are examined using hierarchical multiple regression equation.

Chapter 6 – Discussion: In this chapter we summarize the research findings corresponding to the hypotheses we proposed in Chapter 3. After that, we present and discuss the possible explanations to these results.

Chapter 7 – Conclusions and Future Study: A brief summary of our research findings is presented in this chapter. Contributions and implications of our research both to researchers and practitioners are addressed subsequently. Finally we discuss the limitations of this study and point out the potential future research directions.

In sum, our research process and corresponding chapters are illustrated in Figure 1.1.

**Part A- Focus & Review**:

Establish research focus on platform-based product development; review the related literature.

**Part B- Hypotheses Development, Survey Implementation and Data Analysis**:

Hypotheses are developed based on existing literature together with a series of exploratory interviews conducted in the field; a large-scale mail survey method is used in our research; structure equation modeling is applied to analyze our multivariate data and examine our theoretical model; hierarchical multiple regression equation is used to test the moderating effects

**Part C- Discussion and Conclusions**:

Discuss about the research findings, address the contributions of our research and give the potential future research directions

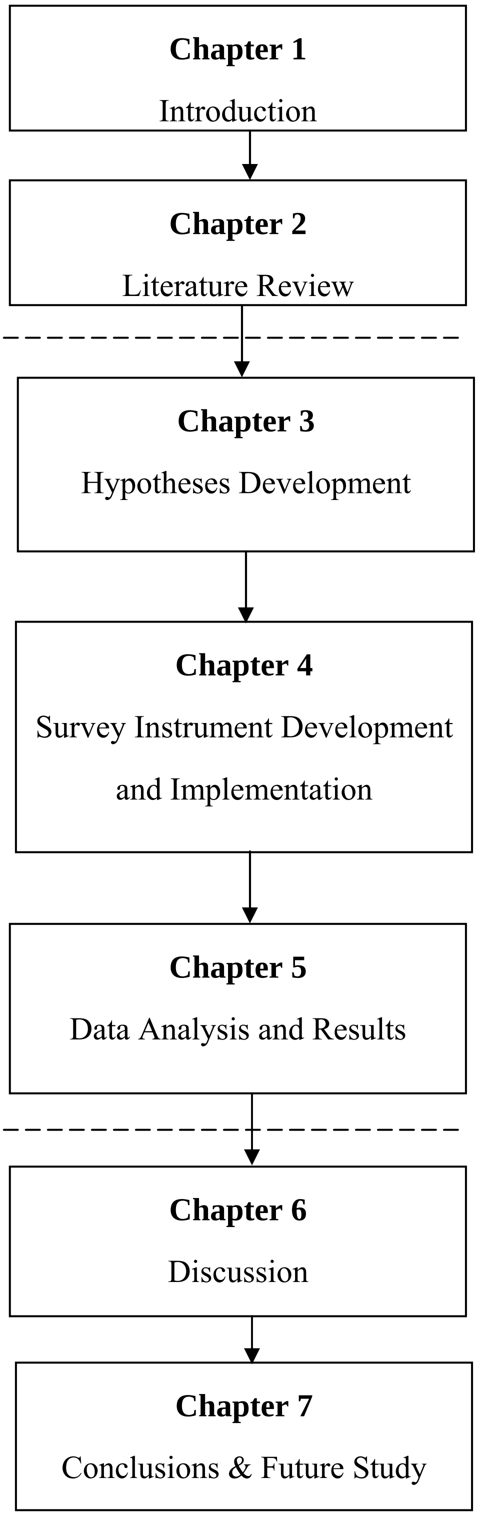



Figure 1.1 Structure of the dissertation

# CHAPTER 2 Literature Review

## 2.1 Introduction

In this chapter, we present our literature review which is conducted using the following systematic approach. We first focus on the relevant literature of modular product development, which is the basis and requirement for platform-based product development (Baldwin and Clark, 1997; Halman et al., 2003). The literature of platform-based product development is then reviewed. Because platform-based product development can be regarded as a powerful tool that contributes to firms' competitive advantages (Meyer and Lehnerd, 1997), the competency-based theory is examined. Subsequently, in order to improve platform-based product development performance, an extensive literature review of success factors in new product development is presented. This review is followed by a discussion of the limitations of previous studies. The chapter ends by introducing the research questions based on issues found in the literature review.

During our literature review, to identify relevant previous studies, a key word search has been conducted of electronic databases ABI/Inform, using such words as "modularity", "modular product", "platform", "product families", "competency", "resource-based", "management strategy", "product performance", "success factor", "environment uncertainty" and so forth. Appropriate citations in references in identified studies are searched and manual searches of leading English-language technology and management journals publishing about product innovation and product development management are also performed. These journals include Academy of Management Journal, Academy of Management Review, Management Science, Decision Science, Strategic Management Journal, Journal of Product Innovation Management, IEEE Transactions on Engineering Management and Research Technology Management. In addition, other relevant sources were also searched, such as books, working papers and journals to find some underlying theories, such as new product development performance, competency-based view as well as knowledge management. The topics as mentioned above come from very diverse journals and from a large number of different disciplines and, unfortunately, show strong variation in approaches used, aspects covered and even in the vocabulary used.

## 2.2 Modular product development

The traditional approach to product competition and manufacturing relied on minimizing variety, lowering cost, and achieving consistent quality. This approach proved appropriate in conditions of both stable technologies and stable market preferences (Worren et al., 2002). More variety was always associated with higher unit costs, due to a correspondingly lower volume for each item and higher complexity of development activities as well as manufacturing activities. This is because the products are designed with many interrelated components that made the overall design time-consuming and costly to change, since change in one component required corresponding changes in other components (Sanchez, 1995). However, as customer demand becomes more heterogeneous, the need for reconfiguration also increases, especially in an uncertain market (Moore, 1991). A challenge for these firms is to find ways to develop innovative, high-quality products and yet minimize development and production costs (Cusumano and Nobeoka, 1998). A different approach for product architectures called modular architectures has been suggested (Sanchez and Mahoney, 1996). This approach enables firms to minimize the physical changes required to achieve a functional change in a product. Unlike in integrated design, in modular design, changes in one component do not lead to changes in other components when the product architecture is designed properly.

According to Ulrich (1995, pp.419), product architecture is defined as "the scheme by which the function of a product is allocated to physical components". The composite interaction of these functions determines the typology of product architecture.

Modularity is put forward as a product design strategy aimed at defining a standardized set of interfaces among components (Ulrich, 1995). Each component is allocated a specific function to be performed with respect to the given interfaces that are not allowed to change during a certain period of time (Ulrich, 1995). In an integral architecture, there is a complex mapping between physical components and functional elements, and the interfaces between components are coupled; a modular architecture is instead characterized by a one-to-one mapping between physical components and functional elements, and the interfaces between components are de-coupled (Ulrich, 1995). In contrast to modular products, in integral products, multiple functions can be achieved with a single component or with multiple components, but it is hard to identify a simple relationship between functional and physical structure in integral products. Compared to the situation of modular product development, staff and organizations producing integral products must interact frequently and closely to optimize the performance of their products (Ulrich, 1995; Fujimoto et al., 2001). In addition, modularization contributes to the ease of disassembly and reassembly, allowing easy construction of different products or systems (Chen and Liu, 2005). This enables more variation and flexibility of the final products (Baldwin and Clark, 1997). Table 2.1 presents a comparison between modular and integral product architecture designs.

According to Schilling's (2000) modular system theory, both heterogeneity in customer demands and ability to assemble product components are positively associated with the levels of modularity. It also enables the benefit of allowing parallelism in design and testing (Baldwin and Clark, 2000). Modular design structures are most favored over integrated structures when flexibility and rapid innovation are more important than overall performance (Ulrich and Eppinger, 2002). Therefore, companies wanting to emphasize product change and variety, flexibility and upgradeability may well choose a modular architecture (Brusoni et al., 2001). In this way, companies may cope with rapidly changing markets, technologies and competitive spaces (Baldwin and Clark 1997; Sanchez 2000).

Table 2.1 Tradeoffs between modular and integral product architecture designs (Mikkola and Gassmann, 2003)

| Benefits of Integral Designs | Benefits of Modular Designs |
|---|---|
| Interactive learning<br>High levels of performance through proprietary technologies<br>Systemic innovations<br>Superior access to information<br>Protection of innovation from imitation<br>High entry barriers for component suppliers<br>Craftsmanship | Task specialization<br>Platform flexibility<br>Increased number of product variants<br>Economies of scale in component commonality<br>Cost savings in inventory and logistics<br>Lower life cycle costs through easy maintenance<br>Shorter product life cycles through incremental improvements such as upgrade, add-ons and adaptations<br>Flexibility in component reuse<br>Independent product development<br>Outsourcing<br>System reliability due to high production volume and experience curve |

Similarly, Meyer and Utterback (1993) reported that, by means of changing the component modules in a modular product, firms can introduce new products into the market or do product upgrading with limited efforts, shorter lead time and lower costs. That is why many firms are now pursuing modular product architecture design strategies. They want to shorten new product development lead time, to introduce multiple product models quickly with new product variants at reduced costs, and to introduce many successive versions from the same product line with increased performance levels (Mikkola and Gassmann, 2003). Table 2.2 shows the motivation of choosing modularization to meet these new product trends above, as well as some other acknowledged trends from recent literature.

The contribution of the modular approach also highlights the enabling role of flexibility, which can be increased through the recombination of modules, while costs and complexity are contained by reusing the same, standard modules across models (component sharing) or model generations (component carry-over). In this way, modularity can greatly enhance the ability to meet diverse demands with diverse system configurations. Firms then can more quickly adapt to diverse customer needs and changing environments.

Table 2.2 Driving forces for using modular product development (Wang et al., 2004)

| Trend | Benefits of modularization |
|---|---|
| Trend 1: Products be on market faster | Make the modules of the product separately and manufacture different modules at the same time (Feitzinger and Lee, 1997) |
| Trend 2: Customer demands on Quality and Reliability increase | Potential production and quality problems can be diagnosed and isolated earlier (Feitzinger and Lee, 1997) |
| Trend 3: Shorter life cycles | Changes to the product are easily accommodated, desired changes to a functional element can be localized to one component (Ulrich, 1995) |
| Trend 4: Create more new products and more variants per product | Maximize the number of standard components it uses in all forms of the product, which allow a great variety of possible products to be assembled (Feitzinger and Lee, 1997) |
| Trend 5: Increasing technological intensity | Modular architecture makes the interfaces of the components well specified and standardized, enabling outsourcing of non-core activities (Sanchez and Mahoney, 1996) |
| Trend 6: Globalization and collaboration | More collaboration in product design on module level, while keeping core competency (Sanchez, 1995) |

On the other hand, diverse customer needs and changing environments may also cause some changes in modular product development. Technological uncertainty, which refers to the degree of a firm's familiarity with the given technology or degree of change in the technologies relative to the products (Tatikonda and Montoya-Weiss, 2001), is high when technology is rapidly changing (Moriarty and Kosnik, 1989). Market uncertainty refers to ambiguity about the type and extent of customer needs that can be satisfied. Market uncertainty is often found in a fast-changing market or an emerging market (Moriarty and Kosnik, 1989).

Concluding: current modularity theories pay insufficient attention to the effects of dynamics of technological and market uncertainties, notably when technologies keep changing fast and unpredictably, leading to unstable interface standards and design rules. Few studies that we have reviewed discuss the impacts of such technology and/or market turbulence on modular product development.

## 2.3 Platform-based product development

In our study, we follow Meyer and Lehnerd (1997) who define product platform as "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently created" (p 39). The definition of "module" in modular product development is defined as a component that is allocated a specific function to be performed with respect to the given interfaces that are not allowed to change during a certain period of time (Ulrich, 1995). Because modularity leads to greater flexibility on a system by enabling modules to be recombined in different ways for different functions through mix and match (Baldwin and Clark, 1997), when a group of modules form common functional subsystems with subsystem interface that can be leveraged in a series of related products, these grouped common modules are usually considered as the product platform, including common functional subsystems and subsystem interfaces (Meyer and Lopez, 1995; Meyer and Lehnerd, 1997). These products are developed based on similar requirements and require only minor changes on product and/or process level (Wheelwright and Clark, 1992). Thus, such a group of differentiated products, which satisfy segmented market needs using a common product platform, is also called a product family (Meyer and Utterback, 1993; Sanderson and Uzumeri, 1995).

Platform-based product designs with clear interfaces between embodied modules allow the firms to rapidly and efficiently build their product families (Tabrizi and Walleigh, 1997). Related advantages are to not only facilitate a reduction in cost of goods for product lines, but also provide opportunities to leverage current product technology and functionality into new markets (Meyer and DeTore 2001), as well as to provide cost-effective variety (Lee and Tang, 1997; Sanderson and Uzumeri, 1997; Krishnan and Gupta, 2001).

Using the platform-based paradigm, products are easily and efficiently derived through addition, exclusion, or substitution of one or more modules (Farrell and Simpson, 2003; Ulrich, 1995). Compared to conventional product development, where at any one period only one product is developed, product platforms can offer a number of benefits if applied properly and successfully, such as reduced development time, reduced development costs and system complexity and improved flexibility for upgrading (Simpson et al. 2006). Literature within the past decade has presented applications of platforms for various types of products across industries, such as computer systems (McGrath, 2001), automobiles (Nobeoka and Cusumano, 1997), and portable tape players (Uzumeri and Sanderson, 1995). This trend can also be seen in Honda's sharing of chassis and many other subsystems between its passenger vehicle product families (the Civic, the Accord, and the Acura), and its SUV CRV vehicles (Meyer and Dalal, 2002). In addition, the concept of product platform has also been widely applied in software products, such as the Macintosh operating system, Microsoft Windows and Visio graphics-charting software (McGrath, 2001; Evans, et al. 2005; Meyer and Seliger, 1998). The platform composed of subsystems and interfaces between subsystems also serves well for software and the architecture of software platform is almost the same as that of a physical platform (Meyer and Lehnerd, 1997; Meyer and Seliger, 1998). Therefore, the approach of leveraging existing platforms through derivative product development applies equally to the management of software product families (Meyer and Lehnerd, 1997).

However, while the benefits of modular and platform-based product development are well documented (e.g. Sawhney, 1998; Muffatto and Roveda, 2000; Mikkola and Gassmann, 2003; Halman et al., 2003), a clear gap in literature still exists when it comes to understanding how to implement and manage product families and their successive platforms (Halman et al., 2003; Jones, 2003). According to Meyer (1997, pp. 17), "product platforms must be managed" and "robust product platforms do not appear by accident". As shown in Hauser's (2001) 5-year study at one high technology firm, if the platform approach is not applied properly, such approach does not improve profitability. Similarly, Krishnan and Gupta (2001) also report that high design costs and low product quality can happen when using platforms. Therefore, in order to gain more benefits effectively from the platform approach and to achieve the desired performance, we need to know the key attributes that make it successful and how to manage them.

In spite of the importance of the management of product platform, which has been emphasized in academic and managerial publications recently (e.g. Skold and Karlsson, 2007; Koufteros et al. 2005; Meyer and Mugge, 2001; Uzumeri and Sanderson, 1995), systematic empirical investigation of the management of platform-based products is still in an early stage and the related management practices have not been addressed specifically (Nobeoka and Cusumano, 1997; Jones, 2003). Thus, there is a need to conduct more empirical research to understand the relationships between management practices in platform-based product development and product platform performance (Kim et al., 2005). In particular, in a technologically dynamic environment, firms may face challenges managing their platform-based product development. We cannot find these answers in current literature. Therefore, it remains difficult for companies to anticipate the consequences of risky platform decisions in advance (Halman et al., 2003).

In addition, Meyer et al. (1997) provides a set of metrics to measure the performance in the context of product family development, which takes into consideration the derivative products as a whole. However, maybe because these metrics largely rely on the real data from each product family, they have not received much attention and have not been applied widely. Another drawback of these metrics is that they are restricted to one firm and lacks the comparison of the effectiveness with competitors, which may lead to a company fail to renew their platform in a timely manner (Halman, et al. 2003).

## 2.4 Competency-based theory and firm competitive advantage

Competency is not a new concept and has its origin in Selznick's (1957) sociological analysis, in which it refers to what is better in an organization than other organizations (Eriksen and Mikkelsen, 1996). However, the competency concept did not really blossom until the early 1980s (Mintzberg, 1990), after Porter (1980) proposed his competitive forces model in a more analytical approach in the strategic management field (Eriksen and Mikkelsen, 1996). Especially since the end of 1980s, complementing Porter's well-known competitive strategy theory (Porter, 1980; Porter, 1985), competency theories have received increasing attention (e.g. Prahalad and Hamel, 1990; Hamel and Prahalad, 1994; Mills et al. 2002). The competency perspective has been widely accepted and appears in popular management and scholarly journals, such as Strategic Management Journal, Journal of Management, Harvard Business Review, the Economist and even the Weekly (Foss, 1996) and in "the dominant perspective on firm strategy today" (Foss, 1996, pp.1). It is interesting to note that different phrases have been used by researchers (Leonard-Barton, 1992), such as "distinctive competences (Snow and Hrebiniak, 1980; Hitt and IreIand, 1985), core or organizational competencies (Prahalad and Hamel, 1990; Hayes, Wheelright and Clark, 1988), firm-specific competency (Pavitt, 1991), resource deployments (Hofer and Schendel, 1978), and invisible assets (Itami, with Roehl, 1987)".

According to Mills, et al. (2000), "a competence is an ability to do something" (pp.9). More specifically, competency is the capability of structuring and using resources for productive purposes that potentially provides a competitive advantage (Grant, 2005; Christensen, 1996). It can also be described as how well the firm performs its necessary activities, which may be categorized into different organizational levels, such as a firm's corporate core competencies as well as business unit competencies (Mills, et al. 2002; Mills and Platts, 2003). For instance, Prahalad and Hamel's (1990) study examined the "core competencies" used to generate new business at a corporate level. Liedtka's (1999) research focused on the competencies at the business unit level, which was less obvious to competitors or customers but key to enhancing the value and exploitation of the business units' competencies (Liedtka, 1999; Mills and Platts, 2003). The competency concept can also be extended to lower levels in an organization, such as group and individual level (Mills and Platts, 2003; Mills, et al. 2002; Eraut, 1994). Lawson (1999) extended the competency perspective beyond the scope of the firm to the analysis of regional productive systems, and argued that such systems can be usefully conceptualized as firms in terms of competencies because of the similar manner in which they are structured.

Competency theory has been widely applied in different environments (Mills, et al. 2002). Taking a competence perspective may unveil previously unnoticed problems/bottlenecks. For instance, Lado and Wilson (1994) explored the potential of human resource systems from a competency-based perspective, by focusing attention on the HR activities, functions and processes, helping them to enhance the understanding of strategic human resources management. Vickery et al. (1993) used such competency-based view in manufacturing and conclude that production competency has a strong effect on business performance, which help firm to achieve sustained better performance related to its competitors. Therefore, product development management is also likely to be benefited from taking a competence-based approach.

According to Lado and Wilson (1994), firm competencies refer to the specific capabilities that enable firm to develop and implement value-enhancing strategies. Such competency-based perspective can also be applied to product development, which sees a firm's ability to enhance its offerings by building products at lower costs and more speedily than competitions as a vital competence (Foss and Harmsen; 1996, Prahalad and Hamel, 1990; Autio et al., 2000). According to this perspective, companies' competitive advantages lie in "produce more economically and/or better satisfy customer wants by creating greater value or net benefits" (Peteraf and Barney, 2003, pp.311). Similarly, in the context of platform-based product development, product platform competency can be defined as the specific capabilities that enable the platform to develop products more efficiently and produce products more economically based on it. As advocted by Foss and Harmsen (1996), a more precise pricture of product development, including the underlying causes of profitability differences, can be achieved by discussing the empirical results of the success factors in the context of a competency-based perpsective. In platform-based product development, such competencies are tightly associated with the underlying architectures and designs. Therefore, viewing platform-based product development from a competency-based perspective may give a better understanding of what leads to success in platform-based product development.

## 2.5 Success factors in new product development

Many research studies have attempted to discover the critical success factors in new product development (i.e. Cooper, 1984; Johne and Snelson, 1988; Cooper, 1994; Souder and Song, 1997; Benedetto, 1999; Thieme, et al. 2003; Astebro and Michela, 2005). Some have looked at the success factors at project level. For instance, Cooper and Kleinschmidt (1987) highlighted the importance of product advantage, proficiency of predevelopment activities and protocol as the strongest success factors in their study.

Song et al. (1997) found that marketing proficiency, product quality, process skills, project management skills and alignment of skills and needs had a strong, positive influence on new product performance. Cooper (1999) further generated eleven successful action items in new product development from industrial experience. Similarly, Riek (2001) also summarized lessons learned from fifteen case histories and gave suggestions on how to manage technical risks, commercial risks and personnel risks respectively leading to successful new products.

In addition, some researchers focus on the factors influencing new product success and failure in a particular context and/or in order to meet a particular objective. Yap and Souder (1994) provided best practices for managers of small entrepreneurial high-technology electronics firms to enhance their new product successes, such as selecting projects with high synergies, developing products that have little competition and high customer need, applying high quality resources, encouraging early top management involvement and recruiting influential product champions. Some other researchers pay more attention to the success factors in reducing development cycle time. For example, Griffin (1997) found cross-functional teams were important to accelerate new product development especially when developing novel products, and a formal development process was important when developing complex products. Kessler and Chakrabarti's study (1999) showed that clear time-goals, longer tenure among team members, and parallel development increased development speed, whereas design for manufacturability, frequent product testing, and computer-aided design systems decreased speed. Based on a comprehensive review of these studies, Montoya-Weiss and Calantone (1994) summarized a list of typical success drivers associated at the project level shown in Table 2.3.

However, according to Cooper and Kleinschmidt (1995), success at the firm level may be somewhat different from success at the project level. There may be some firm level practices not observed or measured when the unit of analysis is the project.

Table 2.3 Factors found to drive new product success at the project level (Montoya-Weiss and Calantone, 1994)

| | |
|---|---|
| **Strategic Factors** | Product advantage; Technological synergy; Marketing synergy; Company resources; Strategy of product |
| **Development Process Factors** | Proficiency of technical activities; Proficiency of marketing activities; Proficiency of up-front (homework) activities; Protocol (product definition); Top management support; Speed to market; Financial/business analysis |
| **Market Environment Factors** | Market potential/size; Market competitiveness; External environment |
| **Organizational Factors** | Internal/external relations; Organizational factors |

Therefore, the determinants of success also need to move from project level of analysis to the firm level (Cooper and Kleinschmidt, 1995). In their study, Cooper and Kleinschmidt (2007) identified four key drivers of performance in product development at firm level, such as a high-quality new product process, the new product strategy for the business unit, resource availability, and R&D spending levels. Furthermore, based on the five broad categories of company's overall new product performance proposed by Cooper and Kleinschmidt (1995), Ernst (2002) gave an excellent review of these empirical studies of success factors and classified each factor into one of the five following categories: (1) new product development process, (2) organization, (3) culture, (4) role and commitment of senior management, and (5) strategy. Similarly, Cormican and O'Sullivan (2004) also grouped five key success factors to build their framework for product innovation management. They are (1) strategy and leadership, (2) culture and climate, (3) planning and selection, (4) structure and performance, and (5) communication and collaboration.

In sum, previous studies of the successful management factors in new product development are either at the single project level or at the firm level. Our literature review suggests that researchers have largely ignored the management practices in platform-based product development and have neglected the unique characteristics challenges in platform-based product development. For example, using paltform-based paradigm, products are easily and efficiently derived through addition and exlcusion, so the management practices in platform-based product development should consider such a group of similar products as a whole, but at the same time also address the differentiation between these products. If the platform approach is not applied properly, such approach does not improve profitability (Haurser, 2001) and high design costs and low product quality can happen (Krishnan and Gupta, 2001). As argued by Cooper and Kleinschmidt (1995), success at the firm level may be somewhat different from success at the project level. The same reasoning can be made here. The success factors which are applicable to platform-based product development might also be different from findings found either at the project level or at the firm level. This is consistent with the view of Balachandra and Friar (1997, pp. 282), who advocate that "a factor may be helpful in leading to success in some contexts but may lead to failure or be unimportant in a different context" because they found "several important factors deemed significant for successful product innovation can vary not only in magnitude but also in direction depending on the context". Therefore, further studies are needed.

## 2.6 Conclusions and research questions

After an extensive literature review, several issues have been revealed that limit our understanding of platform-based product development.

Firstly, there are some studies in the context of platform-based products, in which the benefits are presented and several characteristics of platform-based product development are illustrated (e.g. Krishnan and Gupta, 2001; Tatikonda, 1999; Kim et al., 2005; Jones, 2003). However the key attributes required for platform-based product development that may help companies win a competitive advantage, are still not very clear. Following Wiemann and Backlund (1980), revealing the elements of product platform competencies could be important because they may serve as operational definition of competency in the context of platform-based product development and also provide information for testing and instructional strategies.

Secondly, most of the successful management practices and success factors in new product development, either at the single project (product) level or at the firm level (Johne and Snelson, 1988; Ernst, 2002). The systematic empirical investigation of the management of platform-based products is still in an early stage (Nobeoka and Cusumano, 1997; Jones, 2003). Although success factors and management strategies have been summarized in previous studies, for the singular product management approach, they may not be appropriate in the context of platform-based product development (Tatikonda, 1999). It is not certain that applying such singular product management approach to individual products developed using a platform-based approach may lead to a reduced overall performance of platform-based product development (Tatikonda, 1999). In addition, though aspects, such as multibrand platform management (Skold and Karlsson, 2007) and platform implementation in practice (Halman et al., 2003), have been considered in previous research, there are no clear answers yet regarding the best management practices applicable in the context of platform-based product development. Moreover, examining the success factors in the context of competency-based perspective may give a better understanding of the underlying reasons for performance differences (Foss and Harmsen, 1996).

Thirdly, the effects of management practices could also be affected by a turbulent environment (Bstieler, 2005; Yap and Souder, 1994). Therefore, different practices may be required in different environments. Such effects also trigger a researchers' call for exploring different environments in product line management strategies (Jones, 2003). In our study, we refer to the turbulent environment as the environment with perceived instability of the technology and the unpredictability of rapid change of the technology, which is also called technologically turbulent environment. Because the turbulent environment that originates from technologies may impact product development performance (Bstieler, 2005), as well as we found in Haurser's (2001) 5-year study, at one high technology firm, if the platform approach is not applied properly, such approach does not improve profitability. Thus consideration of technologically turbulent environment is important to the analysis in our research. Unfortunately, all of these issues have not been explored sufficiently by current studies. Therefore, we raise our research questions as follows:

**How can firms improve their platform-based product development performance, from a competency-based perspective?**

Which can be further decomposed into three sub-questions:

**1) What are the elements of product platform competency, and how do they affect platform performance?**
**2) What are the antecedents to these elements, and how do they affect these elements of product platform competency?**
**3) How does technologically environment turbulence affect product platform competency?**

Therefore, our research is directed at building a framework on managing platform-based product development from a product platform competency perspective. Based on the existing literature as well as complementary interviews in companies, the framework along with a set of hypotheses are developed and presented in the next chapter.

# CHAPTER 3 Hypotheses Development

## 3.1 Introduction

In this chapter, we elaborate the reasons and how we combine field studies as a supplement to existing literature to develop our hypotheses. Next, based on existing literature and our interviews in four leading technology-driven companies, three sets of hypotheses are proposed for empirical testing. They are presented in the following sequence: product platform competency and its impacts on platform technical performance in Section 3.3.1; antecedents of product platform competency—management practices in platform-based product development in Section 3.3.2; and moderating effects of technologically turbulent environment in platform-based product development in Section 3.3.3.

## 3.2 Exploratory interviews

Because of the lack of empirical exploration in this field, in addition to reviewing existing literature, a series of exploratory interviews were conducted in four leading technology-driven companies as a supplement and help us to generate our hypotheses. The purpose of these exploratory interviews is threefold. The first purpose is to understand the context of platform-based product development in practice (Xie et al., 2003). The second purpose is to verify the constructs we obtain from literature from an industry perspective. The third purpose is to generate new measurement items related to the corresponding conceptual constructs in our study (Xie et al., 2003). Such field studies are well suited for understanding the how and why of phenomenon (Klein Woolthuis et al., 2005; Yin, 1994) and highly relevant when dealing with problems not previously addressed in the literature (Aggeri and Segrestin, 2007). This combined approach allows us to incorporate the findings of past research with practical experience from industry, and generate our hypotheses more robust.

All the interviews were conducted from companies in the Electronics and Electrical industry. As opposed to industrial sectors such as pharmacy and the chemical industry, most of the products in the Electronics and Electrical industry have modular based product architecture and use platform approach. We have the criteria used for selecting the firms (1) substantial experience in new product development and in apply platform approach, (2) developing relative complex technology-driven products, (3) leading companies in respective markets for their products, which may assure us that their management strategies are more successful compared to other not successful companies. Table 3.1 is the summary of the company profiles and the short descriptions of the four case companies who participated in our field studies. These companies are leading technology-driven companies in their respective markets. All interviews were conducted in the Netherlands. To maintain confidentiality, the companies names are disguised as A, B, C, and D.

In total, we conducted a series of 28 in-depth interviews attended by interviewees involved in platform-based product development. They come from different functional background, such as platform management, project management, R&D, systems engineering, quality and reliability engineering, marketing, purchasing and manufacturing.

Table 3.1 Summary of company profiles and descriptions

| Company | Product | Employees (2004) | Net Sales (2004) | Descriptions |
|---|---|---|---|---|
| Company A--Multinational Company | Health-Care Electronic Product | 30,900 | 6,990 million Euros | Company A's primary products included those for heart and vascular disease, neurological disorder, chronic pain, spinal disorders, diabetes, urologic and digestive system disorder, and eye, ear, nose and throat disorders. It had two main product series, the AA-series (AA1 and AA2) and the AB-series (AB1, AB2, AB3 andAB4) pacemakers, both of which were based on one common hardware platform. These pacemakers were very innovative because of the use of software in the systems. They also had a programmer, which supported the pacemakers and was used for the user interface. |
| Company B--Multinational Company | Consumer Electronic Product | 44, 000 | 4,526 million Euros | Company B developed lamp drivers for igniting and controlling gas discharge lamps for the traditional market, like fluorescent and tubular lamps and high intensity discharge lamps. There were two different kinds of lamp drivers developed, one was the electromagnetic lamp driver and the other was the electronic lamp driver. The product family had the same way of connecting the major electronic components with each other. The topology for the different lamp drivers, although designed for the different world regions, was the same. The different drivers have largely similar topology, component based and manufacturing process. |
| Company C--Local Company (Netherlands) | Electrical and Mechanical Equipment | 1,200 | 332 million Euros | Company C focused on providing fast, efficient, reliable and labour-saving goods handling equipment in distribution centres and express parcel sortation facilities, and for baggage handling at airports through providing Automated Material Handling Systems. It applied the concept of platform development for their product families like family CA, and family CB, which referred to the specific set-up of the production system to produce easily the desired variety of products. The production system included flexible equipment, for example, programmable automation or robots, computerized scheduling, flexible supply chains and carefully designed inventory systems. |
| Company D--Multinational Company | Electrical Equipment | 30,800 | 5,884 million Euros | Company D developed high-end cardio vascular systems. These systems performed two functions, an intervention function that was used in cardiology, and a diagnostic function that was used in radiology. There were four different product types available from a common platform for the market. They were named DA; DB; DC and DD.<br>All these products consisted of a detector, tube, C-arm, table and cabinet; which were the standard layout of all the systems. |

Prior to the interview, a questionnaire was sent to the interviewee for him or her to prepare the interview. We used semi-structured interviews to probe deeper in the what, how and why questions. For each interviewee, the questions were adapted to his or her specific role in the platform product development project and his or her contextual setting. In the interviews, we asked interviewees about their platform and its derivative product development process, development team organization, knowledge sharing proficiency, as well as their platform-based product design strategy and final performance measurement. During the interviews, one investigator was primarily responsible for asking questions listed in interview protocol, and the other investigators took notes. The interviews were recorded and the recordings were used to supplement the interview transcripts. The average duration of the interviews was one hour and a half.

Related to the three purposes of our interviews that we mentioned earlier, a summary of findings is presented in Table 3.2. The interviews provide first hand information on how platform is managed in companies, and provide the basis for several hypotheses which we will develop in the next section. Similarly, findings from the first purpose are also used to generate new measurement items (i.e. the third purpose of conducting the interviews), which we will elaborate in Section 4.2.

Table 3.2 Summary of findings from interviews

| **Purpose One—Understanding platform-based product development**<br>**Observations from our interviews** | **Purpose Two—Corresponding constructs to be verified**[#] | **Purpose Three—New measurement to be generated**[*] |
|---|---|---|
| "The initial time and cost of developing a common platform were usually larger compared to developing a single product…We spent seven years to develop our initial platform and the first product. Based on it, we have produced 6 products to date, which usually takes 6 to 9 months development time for one new model at low cost" (Company A) | Extensibility of platform-based products | |
| "It involved high cost and uncertainty of integrating new modules, so we use as many on the shelf modules as possible" (Company B)<br><br>"New building blocks have different lifecycle, thus we reuse as old ones as possible" (Company A)<br><br>"It is necessary there are some features to be offered similarly according to customers' preferences, therefore some common functional modules are reused" (Company C)<br><br>"We try our best to share components among different products to reduce the development costs and lead time" (Company D) | Reusability of subsystems of platform-based products | We usually follow a strategy to design common functional modules to be used in several products derived from this platform. |
| "Challenges were that we were looking for several different kinds of products sharing one platform…If the hardware became unsuitable, the updates became too expensive…So we finally decided to switch from the OS2 operating system to the XP window based to integrate more applications in future " (Company A)<br><br>"In the platform design we needed to take different demands into account; saw if it was feasible to make the platform have common interfaces, and build the platform for all regions. After checking the feasibility to produce all the products for the different regions from this platform, we reached milestone B. At that time platform development was completed, we must be sure the products can be derived from such platform for all the regions" (Company B) | Compatibility of subsystem interfaces of platform-based products | It is quite easy to add new functional modules without changing other parts to develop new derivative products from this common platform.<br><br>There is a high degree of common interfaces among different products derived from this common platform |

| | | |
|---|---|---|
| "Time-to-market is an indicator which is used to measure the product development based on individual product…. We had no particular performance indicators for our platforms" (Company A );<br><br>"Customer satisfaction could be an important performance indicator to us….There are no special platform measures" (Company B)<br><br>"Time to market and field rate of return are measured for our products. … We do not measure the platform performance directly" (Company C)<br><br>"We usually use return on investments made in our R&D department….No specific platform measurement is applied" (Company D) | Platform technical performance | |
| "Our development process is very well documented and all of our engineers should know such process" (Company A)<br><br>"We developed our product platform in a systematical manner and regularly check our development progress in a time base" (Company B)<br><br>"Start with a core cross-functional team and need to go through several milestones using standard procedures" (Company D) | Formalized platform-based product development process | We regularly check the development progress of our products derived from this platform in a time base<br><br>We monitor the development progress of our products derived from this platform using standard procedures |
| "There were abundant database of guidance document of all related products accessible" (Company C)<br><br>"It is easy our staff to discuss with other product engineers through meetings, emails or online forum, especially within the same product family" (Company D)<br><br>"We organize our development team members from different product series to share their experience at department meetings." (Company B)<br><br>"We exert efforts to leverage our existing knowledge from past products into new ones" (Company A) | Design knowledge dissemination across platform-based products | |

| | | |
|---|---|---|
| “We largely rely on our past experience in the development team. Such experience is particularly helpful in platform-based product development as most of the problems have the same root cause….So we usually make our development team stable from inception till launch in developing a series of products from the same platform” (Company C)<br><br>“We redesigned a product because of the little experience of new employees, and in the end we had to assign the experienced staff to join the project again” (Company B) | Continuity of platform-based product development team | A same team was accountable from inception through launch for a series of products derived from this platform |
| “Next generation platform always needs to hold all the old functionality of the existing product platform. It causes functionality growing and growing. We need an expert to lead our team to determine what next to be built and scope new functionality constrained by marketing priority and technology. Most importantly, he may use his previous knowledge to solve the new problems by lease resources, which reduces our development cost greatly” (Company B) | Existence of a champion in platform-based product development | |

[#] This will be further elaborated in Section 3.3

[*] This will be further elaborated in Section 4.2

## 3.3 Hypotheses and theoretical model

### 3.3.1 Product platform competency and its impact on platform technical performance

***Product Platform Competency***

Various definitions have been proposed in the platform development literature (Muffatto and Roveda 2000). In this study, we follow Meyer and Lehnerd (1997) who define product platform as "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently created" (p 39). As a result of which, products are derived through addition, exclusion, or substitution of one or more modules (Farrell and Simpson, 2003; Ulrich, 1995). Such practices often result in families of products which share similar subsystems. Therefore, flexibility in product design and efficiency in product development and realization are the expected benefits from the application of product platform concept (Halman, et al, 2003).

According to Lado and Wilson (1994), firm competencies refer to the specific capabilities that enable the firm to develop and implement value-enhancing strategies. Similarly, in the context of platform-based product development, product platform competency can be defined as the specific capabilities that enable the platform to develop products more efficiently and produce products more economically based on it. Such capabilities in platform-based product development are tightly associated with the underlying architectures and designs and are the basis of products (Meyer and Utterback, 1993).

***Extensibility of platform-based products***

In order to maintain a viable product platform, firms need to ensure enough scale economies and scope economies to build products if it is not at the expense of product performance (Garud and Kumaraswamy, 1995; Kim et al., 2005). Firms produce fewer derivative products from their platforms need to introduce costly platforms at a more rapid rate to offset it (Jones, 2003). Therefore, when firms know how to rationalize their existing product platform, the extensibility of platform-based products, which we defined as the capacity of the platform to produce derivative products, could be critically important as it represents one aspect of product development effectiveness. This is consistent with Barney et al. (2001), who viewed the abilities to change quickly and to be alert to changes at lower cost than others as a source of competitive advantage. As a consequence, we consider the extensibility of platform-based products as one of the main elements of product platform competency to generate derivatives cheaply and quickly. That is, the more derivative products that can be extended from the platform, the greater the product platform has been made use of and the more competency the product platform has, and vice versa, the less the derivative products that can be extended from the platform, the less power the product platform has.

The above can also be confirmed by the interviews in our field studies. Platforms were designed so that new products could be derived within a short lead-time with lower cost. This was a goal that almost every interviewee mentioned to be important for his or her company. Due to the high cost incurred by the initial platform design compared to developing a single product, firms want to leverage their platforms as much as possible to produce follow-up products at little extra cost. As illustrated by the technical manager in company A, it took them seven years in total to develop the platform and its first product, derived from platform. But as they could continuously produce a series of successive products from that platform, both the average development cost and cycle time were much lower than their competitors eventually. Therefore, their platform competitive advantages were greatly achieved thanks to the high extensibility of their platform-based products.

***Reusability of subsystems and Compatibility of subsystem interfaces of platform-based products***

In addition, according to Ulrich (1995), a product can be composed of two major elements from the architecture perspective: physical components and interfaces. The component is usually named as a functional module in modular product and can be viewed as a subsystem from the platform architecture perspective. Therefore, a platform-based product can be considered as a technical architecture composed of subsystems and interfaces. This is consistent with Meyer et al. (1997, pp.91), who said "a product platform design consists of a basic architecture, comprised of subsystems or modules and the interfaces between these modules" and Meyer (1997, pp.17), who thought "product platform is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced". The technical subsystems embody some specific functions while the subsystem interfaces of platform-based products provide the connections among subsystems, as shown in Figure 3.1. They serve as the foundation of the product platform, which can be used across for a stream of products (Meyer and Lopez, 1995; Meyer and Lehnerd, 1997; Halman, et al., 2003; Meyer and Lehnerd 2004). Therefore, the reusability of subsystems and the compatibility of subsystem interfaces of platform-based product interfaces are the other two critical important points for building efficient platform architecture. Therefore, together with extensibility of platform-based products, reusability of subsystems and compatibility of subsystem interfaces are collectively viewed as the three elements consisted of product platform competency in our study.

***Reusability of subsystems of platform-based products***

The reusability of subsystems in platform-based products refers to the using identical product features or subsystems in a group of derivative products (Kim and Chhajed, 2001). One of the main purposes of product platform development in companies is to reduce the time, effort and risk of repetitive design through reusing or sharing as many existing components as possible. As shown in Figure 3.1, Subsystem 2, 3 and 4 are reused across the derivative products from one common platform. Such reusability of subsystems across multiple products makes it possible for firms to create derivative products at minimum incremental efforts when offering similar features according to customers' preferences (Kim and Chhajed, 2001).

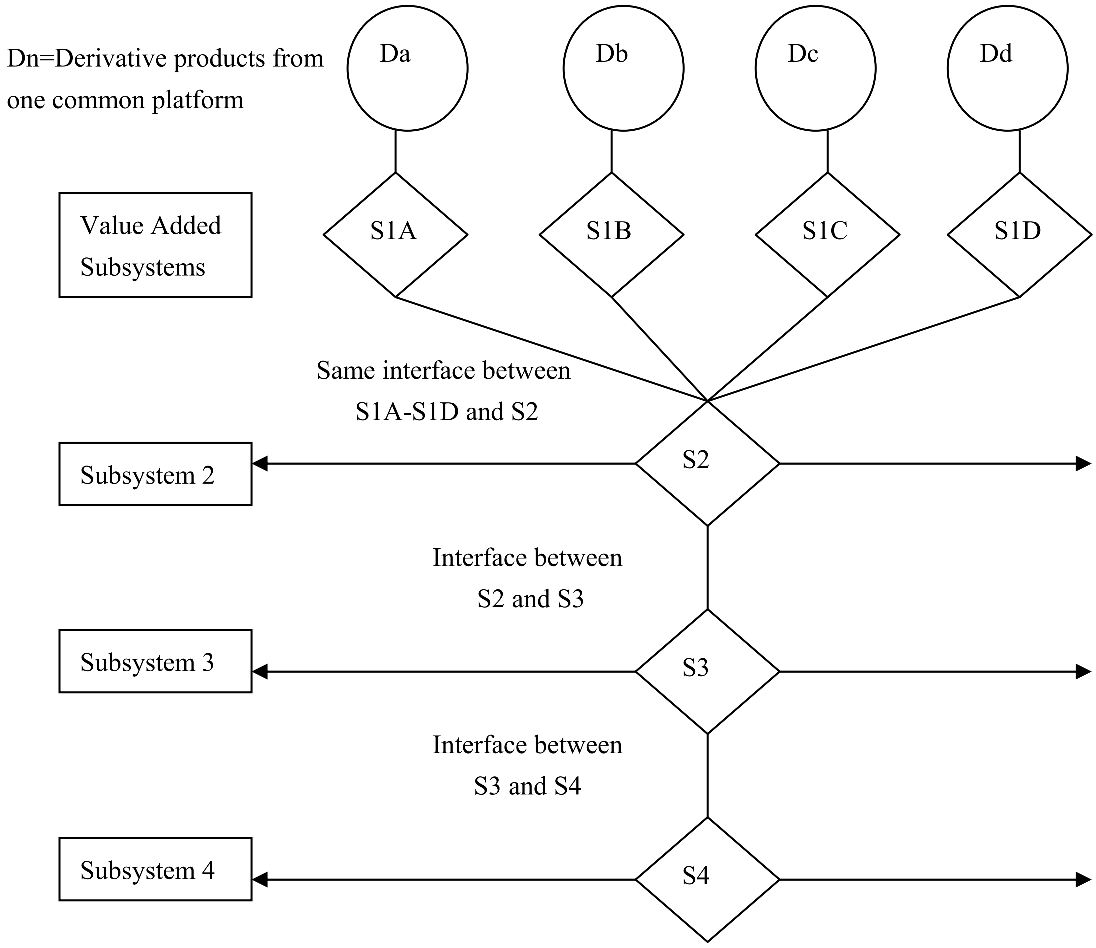



Figure 3.1 Platform-based product subsystems and interfaces (adapted from Meyer and Lehnard, 2004)

In practice, companies in our field studies draw particular attention to share the architecture and the subsystems in their platform-based product design. In company A, one principle of their platform infrastructure design is to make as many building blocks shared as possible. Similarly, company B also applied the strategy of reusing on-the-shelf components. The main reason is that reusing existing components may provide higher reliability than new modules. Obviously, all these four firms were most concerned about the development effectiveness in their platform-based product development and made a good balance of commonality and single customized function. This is because good platform architecture needs a combination of subsystems that can serve as the basis of a stream of platform-based products (Meyer and Lenherd, 2004). To achieve a high level of reuse of design elements has been regarded as a strategy in platform-based product development (Fixson, 2002; Jones, 2003). The power of the platform discipline may only occur when a substantial percentage of subsystems within the platform are common (Meyer and Lehnerd, 2004).

Therefore, the reusability of subsystems actually refers to the ability of reusing or sharing the existing components across the derivative products from one common platform. However, all companies have to make a good balance of commonality and customized functions. In this case, a good product platform should be able to allow the as many as possible subsystems can be shared or carried-over across multi-products, which reflects the reusability of subsystems. Hence, building reusable subsystems that may be shared or carried-over across multi-products is a pre-requisite to construct product platforms. In this way, the reusability of subsystems of platform-based products allows the firm to build its product families rapidly and efficiently (Tabrizi and Walleigh, 1997), which provides opportunities to leverage current product technology and functionality into new markets (Meyer and DeTore 2001), as well as provides cost-effective variety (Lee and Tang, 1997; Sanderson and Uzumeri, 1997; Krishnan and Gupta, 2001). Nokia's advantages in product development efficiency are having large amounts of reusable common subsystems among its product lines, which enables them to provide more models than its competitors during the same period (Funk, 2003). Hence, the reusability of subsystems of platform-based products may help firms to obtain economies of scale. Compared to conventional product development of developing one product at a time, the reusability of platform subsystems enables product platforms to offer a number of derivative products effectively and rapidly, which increases platforms' ability to extend the scope of their products. Thus, we hypothesize the following:

*H1: The level of reusability of subsystems of platform-based products is positively associated with the level of extensibility of platform-based products.*

***Compatibility of subsystem interfaces of platform-based products***

The connections between subsystems are the interfaces, which are the base of product platform architecture for both integrating and disintegrating of platform-based product subsystems and provide the properties for subsystems to interact and correlate to perform full product functions (Meyer and Lehnerd, 1997; Chen and Liu, 2005). Besides the platform-based product subsystems design, the other key feature of platform-based product design is that it allows for changes not just for a single product but rather a series of derivative variants (Rothwell and Gardiner, 1990). An effective architecture is created when the interfaces between functional components are standardized and specified to allow the substitution of a range of subsystems without requiring changes in the designs of other subsystems (Garud and Kumaraswamy, 1995; Sanchez and Mahoney, 1996; Sanchez and Collins, 2001). Today, most technology-focused industries have structured their platform subsystems to perform a gradation of functions (Meyer and Lehnerd, 2004). However, in practice when engineers add new subsystems with new functionality, they sometimes tend to build new interfaces between these subsystems. Such multiplicity of interfaces will cause a tremendous impediment to creating derivative products. Because of changing or adding one subsystem, a lot of related subsystems need to be changed (Meyer and Lehnerd, 2004). Challenges were big for companies that developed platform-based products, which were looking for a series of products sharing one platform. One application manager of company A addressed this point in the interview. Drawbacks of the use of platform development were that the requirements were always uncertain in a longer period of time and when the hardware became unsuitable, the updates became too expensive. Thus, in company A, they decided to switch from the IBM OS2 operating system to the Microsoft XP Windows, in order to integrate more future applications in their product families in future. In company B, they also met with the problems of different requirements from different regions. The project manager explained that "In the platform design we needed to take different demands into account; saw if it was feasible to make the platform have common interfaces, and build the platform for all regions. After checking the feasibility to produce all the products for the different regions from this platform, we reached milestone B. At that time platform development was completed, we must be sure the products can be derived from such platform for all the regions". This is consistent with the views of Thomke (1997, pp. 109), who said "the ability to accommodate evolving design requirements, or having high design flexibility, can be very beneficial, especially in an increasingly competitive marketplace where meeting customer needs and being at the technological forefront are essential to firm success".

From the findings above, we may conclude that no matter how difficult it would be, it is highly valuable to make product architecture more generic in platform-based product development, especially for really new products, leaving enough flexibility for future value added changes, or additions for upgrading, while keeping others stable. As shown in Figure 3.1, the interface between S2 and S1A is also compatible to integrate S2 with S1B, S1C and S1D, without any further changes.

Therefore, compared to conventional product development of developing one product at a time, compatible interface design is important in platform-based product development because it allows new platform-based product subsystems or components to be integrated rapidly and easily, sharing common architecture (Meyer and Mugge, 2001; Meyer, 1997). We refer compatibility of interfaces as the capability of integrating new subsystems. According to Funk (2003), the compatibility between Nokia's GSM900 product interfaces with Nokia's cdmaOne phones contributed to Nokia's success. As a consequence, Nokia may introduce new phones that are several times more than its competitors in a shorter period and at a lower cost when considering the number of different languages and other permutations for different regional markets (Funk, 2003). That is to say, if the platform-based product interfaces are designed properly with high level of compatibility, firms may improve flexibility for upgrading and easily develop more products based on the same platform. Hence, the compatibility of interfaces of platform-based products may enable firms to obtain economies of scope for their product platforms—providing more product variety and potential applications. Accordingly, the platform's ability to extend the scope of its derivative products is enhanced. Therefore, we hypothesize the following:

*H2: The level of compatibility of subsystem interfaces of platform-based products is positively associated with the level of extensibility of platform-based products.*

***Platform technical performance***

A good set of metrics may tell the right things to measure and provide a means for collecting the right data (Jandourek, 1996). A broad literature has examined the development performance of individual product isolated from one another (Jones, 2003) and has not attempted to assess the impact of relationships among products in the context of platform-based product development (e.g. Kim et al., 2005). Such situation could also be found in our field studies. None of these companies has specific performance indicators to measure their product platform, most of which are measured in singular product level.

However, this is not accurate since an overall platform development is for the benefits of an entire product family. The measurement on product platform needs to be done on its stream of products based on a common architecture rather than on individual product. On this point, Meyer and his colleagues (Meyer et al., 1997) provide a sound sample of metrics that could be applied in the context of the product family.

Moreover, as Kim et al. (2005) summarized from their study of platform and derivative products, financial and market performance are dependent on the technical performance in the context of product families, and not directly related to the activities in product development process. They further suggested that future investigations should separate the technical and commercial performance. Therefore, in platform-based product development, technical performance is more important and fundamental and it is chosen as the final outcome in our study. Moreover, as claimed by Jones (2003), the emphasis on development speed alone is oversimplified in platform-based product development. The tradeoff between development cycle time and cost must be balanced (Bayus, 1998). Therefore, platform cost performance and cycle time performance are both considered in our study.

In addition, because perceived performance, which is widely used in survey research, captures the perceptions of the respondents that underlie their decision-making processes and permit comparisons across firms and across industries (Song and Parry, 1997), they are more reasonable and appropriate in our study. Therefore, in our study we adapted Meyer and his colleagues' (Meyer et al., 1997) metrics in the context of the product family from real data basis into perceived measures, using technical metrics of platform cost efficiency and platform cycle time efficiency. These two performance metrics indicate the degree to which a product platform allows economical generation of follow-on products rather than from a singular product perspective (Meyer et al., 1997).

As Meyer and Utterback (1993) claimed, higher level of core capability should be associated with higher levels of performance. In the context to platform-based product development, product platform competency represents the specific capabilities that enable the platform to develop products more efficiently and economically. The more products can be derived from the platform, the more associated development costs and time on average may be reduced. This is consistent with the statement of Meyer and

Lehnard (1997), who insist that the power of product platforms is to accommodate new component technologies and variations, consequently to make the firms to create derivative products at incremental cost and time relative to their initial investments in the platform itself. Such product variety from a platform may obtain economies to impact firms' product family performance (Kim et al., 2005). Therefore, we hypothesize the following:

*H3a: The level of extensibility of platform-based products is positively associated with the level of platform cost efficiency.*

*H3b: The level of extensibility of platform-based products is positively associated with the level platform cycle time efficiency.*

### 3.3.2 Antecedents of product platform competency—management practices in platform-based product development

Robertson and Ulrich (1998) have distinguished four categories when defining a product platform. They defined a product platform as the collection of assets that are shared by:

- Components: the part designs of a product;
- Processes: the equipment and design process used to make components or to assemble components into products;
- Knowledge: design know-how, technology applications and limitations, production techniques;
- People and relationships: teams, relationships among team members, relationships between the team and the larger organization.

Here, components refer to the functional parts of a product, which can be regarded as the technical base of a product. Such components could be defined as functional subsystems in the context of platform-based product development and may include the interfaces that make these subsystems work well together. Therefore, "component" perspective is built on the elements of the product architecture and is the basis for a common platform of a product family. This is consistent with the view of product platform competency we identified before, which is tightly associated with the underlying architectures and designs and serves the basis of platform-based products (Meyer and Utterback, 1993). Hence, "product platform competency" is the viewpoint from component perspective, including "reusability of subsystems of platform-based products", "compatibility of subsystem interfaces of platform-based products" and "extensibility of platform-based products".

Regarding the platform-based product development process, because firms did not explicitly differentiate between platform work and derivative product work with respect to development costs and time, the spending for the first product from a platform version was treated as one with the spending for that platform version (Meyer et al. 1997). This is also consistent with the statement of Tatikonda (1999) and Kim et al. (2005), who refer platform as the initial product that is developed and commercialized whereas the derivative products are the follow-up products that are derived from it. Therefore, from this standpoint, we view platform development as part of the initial product development from that platform. Another way to consider this matter is that the architecture comprised of subsystems and interfaces of such initial product has the potential of becoming a platform to serve as the foundation for creating more derivative products (Meyer et al., 1997). Accordingly, processes here refer to the process to develop the products based on a common platform, in which platform development is integrated in the process of developing the first product.

In addition, in order to reach a good design of platform to produce a series of derivative products, firms have to rely on their design knowledge and development process to achieve it. Therefore, design knowledge and development process may directly impact on the design of the architecture of platform-based products. Furthermore, according to Henderson and Clark (1990), organizational structure in which companies develop their product need to closely reflect the architectures of the product itself, which in turn affect the final product performance. Similarly, in the context of platform-based product development, the team organizations may reflect the architectures of the platform and its derivative products they develop, which in turn affect the final platform technical performance.

Accordingly, in line with recent discussions in literature (Meyer and Lehnerd, 1997; Sawhney, 1998; Halman, et al. 2003), we argue that an ideal product platform should be built not only on its technical architecture, but also on a multidimensional core of activities related to the human beings that may improve the design efficiency, such as the process of development, knowledge learning as well as organization management. As Roberston and Ulrich (1998) suggested, only when taken together, these four building blocks constitute the platform. Therefore, besides the **Component** perspective we discussed before, we will investigate key management practices involved in platform-based product development from the other three perspectives respectively: **Process, Knowledge, and Organization** as the antecedents of **Component--**product platform competency**.**

**Process Perspective**

***Formalized platform-based product development process***

According to Sanchez (2004), a platform consists of modular product and process architectures designed to achieve a defined set of business goals. The primary thrust for firms developing a series of products that share a common platform is to gain efficiencies from developing a series of derivative products than a unique product. Based on several field studies, Muffatto and Roveda (2000) conclude that because of the platform's intrinsic feature of developing streams of derivative products, a new platform development process, which is distinctive from traditional single product development process, is preferred. Similarly, Sanchez (2004) also argues, in order to create a truly effective platform, platform designers have to be concerned with all aspects of the product realization process, such as working closely with business strategic managers, interacting intensively with supply chain professionals as well as with manufacturing engineers. Hence, it is not surprising to know "successful new growth platform companies like UPS, P&G, Medtronic, and Inverness had all systematically defined the processes of new growth platform creation and the roles of the various participants" (Laurie, et al., 2006, pp.88). This is also consistent with our findings in three successful large multi-national companies (A, B, D) in the Netherlands, where a complete platform development process is well defined and implemented.

Henderson and Clark (1990) claimed that organizations need to often organize developing and producing processes into structures that closely reflect the architectures of the products they develop. With respect to platform-based product development, the formalized process refers to a well-defined rules and complete development procedures to order the tasks of developing platform-based products. Compared to traditional product development, platform-based product development is complex, involving a great range of activities to be performed by many developers with different technical skills, because of the need to accommodate future derivative products from the very beginning. According to Kleinschmidt et al. (2007), when the level of complexity surrounding the process (i.e. the number and diversity of projects) and the scope of information required increase, a formalized development process is key in ensuring that every element has been identified and taken into consideration. A formalized platform-based product development process tends to be well documented and closely followed by design engineers. In addition, it also allows regular monitoring and easy tracking of the development progress.

Consequently, a formalized process for platform-based product development will help to instill discipline among engineers in ensuring the reusability of their design, which dictates the overall success of platform-based product development. If the same development process is followed, even if different individuals are involved, engineers are less likely to develop radically different products because of the path-dependency effect, thus maintaining compatibility between the various subsystems. The pressure to reduce development time and the requirement to follow standardized development procedures will result in engineers trying to reuse existing subsystems whenever possible, even when faced with new product requirements. This is because these existing subsystems will have been proven in previous derivative products and using such proven subsystems will help engineers to meet tight development deadlines. Hence, the precise specification of process tasks and people in platform-based product development may reduce the variation caused by the above diversities and increase the commonality between products. As a result, this may increase the chance to make engineers reuse the subsystem that have been applied previously as well as design the interfaces more compatible. In addition, going through the same development procedures, engineers are more likely and easily to develop more products with similar required functions based on one common platform, which may increase the extensibility of derivative products consequently. Therefore, we hypothesize the following:

*H4a: Formalized platform-based product development process has a positive influence on the level of reusability of subsystems of platform-based products.*

*H4b: Formalized platform-based product development process has a positive influence on the level of compatibility of subsystem interfaces of platform-based products.*

*H4c: Formalized platform-based product development process has a positive influence on the level of extensibility of platform-based products.*

In addition, by repeating established processing concepts, firms may avoid or reduce the typical start-up cycle time incurred by uncertainty and confusion when developing a new product derived from a same platform (Koufteros et al., 2005). Thus, we further hypothesize the following:

*H4d: Formalized platform-based product development process is positively associated with the level of platform cycle time efficiency.*

**Knowledge Perspective**

***Design knowledge dissemination across platform-based products***

Following Nonaka (1994) and Song et al. (2007), knowledge is defined as justified true belief. It refers to "information that has entered human belief systems and has been validated by experience" (Song et al. 2007). Product platform design knowledge here are those knowledge that enable companies develop and produce new products from platforms. This may also include technology knowledge that has a potential to be incorporated into platform-based products (Bstieler, 2005; Meyer and Lehnerd, 1997). Further, design knowledge dissemination is defined as the process and extent of design knowledge exchange within a given organization (Song et al, 2007). The organization here refers to platform-based product development teams.

A platform provides a base to produce a family of related derivative products that may share common technology in a large measure with previous products and require only minor changes to existing products (Jones, 2003). Therefore, companies may leverage the known resources, knowledge and skills more effectively across a series of products based on one platform, as these new products are adaptations, refinements and enhancements of existing products built on established same platforms (Brentani, 2001). Company B and D have regular meetings among their different product development teams to share both the successful or unsuccessful experience.

Perhaps more than any other form of resource, knowledge is crucial in new product development, especially when viewed from a knowledge management perspective

(Madhavan and Grover, 1998). Therefore, effective knowledge management is likely to be crucial to the success of platform–based product development. For instance, when knowledge on the requirements of customers from different regions and the objectives of the product design are well shared and disseminated, product developers are more likely to ensure that their design can accommodate such diverse and potential changes, thus increasing the reusability of their designs. In addition, when there is a high level of knowledge sharing and dissemination, developers will be more aware of each other's design and are thus more likely to design subsystems which are compatible and the more awareness of design scope and boundaries will be considered in the subsequent products based on one common platform, which results in a higher level of the compatibility of firms' platform-based product interfaces. Finally, when knowledge is well disseminated, product developers become more aware of what the platform is designed for and thus can try to maximize the full potential of the platform. To sum up the above discussion, we hypothesize the following:

*H5a: Design knowledge dissemination across platform-based products has a positive influence on the level of reusability of subsystems of platform-based products.*

*H5b: Design knowledge dissemination across platform-based products has a positive influence on the level of compatibility of subsystem interfaces of platform-based products.*

*H5c: Design knowledge dissemination across platform-based products has a positive influence on the level of extensibility of platform-based products.*

**Organization Perspective**

***Continuity of platform-based product development team***

Team stability is defined by Meyer and Lehnard (1997) as the ownership and empowerment granted for the full term of a project, from conceptualization until commercialization. According to Cooper and Kleinschmidt (1993a; 1993b), the project success rates were higher when the team was responsible from the beginning to the end. It is also consistent with the conclusion of Kahn et al. (2006), who suggested each project needs a core team which remains on the project from beginning to end. In the context of platform development, we should see such concept from a multi-product perspective, which means one platform serves all individual products within a product family, as well as over multiple product generations by a common basis. Hence, in this concern, we extend the concept of team stability from one product to a series of products, where we view it as the continuity of platform-based product development team.

This situation could be reflected by our field interviews. According to the R&D manager in company C, their engineers largely relied on their past experience to find out what to do about the problems occurring in the development process. Such experience was particularly helpful in platform-based product development as most of the problems had the same root cause that called for similar solutions. As a consequence, managers in companies usually like to make the same team responsible for a series of products from the same platform and avoid changing the team.

According to some researchers, organizational memory is a kind of stored knowledge (Moorman and Miner, 1997; Walsh and Ungson, 1991), and utilizing information from past projects is an effective means to use that stored knowledge (Lynn, et al., 1997; Lynn, et al., 2000), which in turn affect product development cycle time (Lynn, et al., 1999; Sherman, et al. 2000). Therefore, the advantage of constant platform-based product development team lies in keeping the competencies developed along with the products and using them across successive generations (Muffatto and Roveda, 2000). In addition, according to learning curve theory (Argote and Epple, 1990), the lower the turnover rate of the workforce, normally the steeper will be the learning curve, which means the continuity of platform-based product development team may promote the knowledge and experience iterative learning across platform-based products and avoid unnecessary rework. This occurs because such continuity could make the development team staff able to keep their previous knowledge and leverage their prior experience much more efficiently and effectively to successive derivative products due to the commonality in a large measure among these products, which subsequently will increase the level of subsystem reusability and interface compatibility across these products. This memory superior will be particularly valuable in the medium to long term when knowledge from developing one product can be used in developing another product with a heavy common base (Garud and Nayyar, 1994; Song et al. 2007). However, such benefits cannot be gained or maintained if key individuals could not work together intensely for extended periods of time (Meyer and Utterback, 1993). They regard such lack of long-term consistency and focus as an essential problem in platform-based product development, because teams where the members have short working time together tend to lack effective patterns of knowledge retaining and information sharing across products.

Therefore, the composition of platform development team should be continuous from the platform conceptualization until several derivative products commercialization, in order to use their prior related experience and knowledge for implementing similar functions across these platform-based products, which in turn may help to increase the reusability of subsystems and the compatibility of interfaces. Meanwhile, such continuity of platform-based product development team is likely to derive more products from the same platform. Therefore, we hypothesize the following:

*H6a: Continuity of platform-based product development team has a positive influence on the level of reusability of subsystems of platform-based products.*

*H6b: Continuity of platform-based product development team has a positive influence on the level of compatibility of subsystem interfaces of platform-based products.*

*H6c: Continuity of platform-based product development team has a positive influence on the level of extensibility of platform-based products.*

Moreover, as Akgun and Lynn (2002) argued, change of team member will cause knowledge loss to the team and to fill the knowledge void with new members may prolong the product development time. Also, when team members work shoulder to shoulder consistently, they may be familiar with one another and improve communication and transmission of so-called "tacit knowledge", and as a result, reducing problem solving cycles and carrying out their work with higher speed. (Muffatto and Roveda, 2000; Akgun and Lynn, 2002). Therefore, we further hypothesize the following:

*H6d: Continuity of platform-based product development team is positively associated with the level of platform cycle time efficiency.*

***Existence of a champion in platform-based product development***

Champions have been defined as someone who "takes an inordinate interest in seeing that a particular process or product is fully developed and marketed" (Rosenau et al., 1996, pp.519). These individuals are distinctive from senior management because a "champion" is not a formal role in an organization (McDonough, 2000). According to Markham (1998, pp. 491), central to the concept of champion is that champions "achieve distinctiveness by accepting risk, vigorously supporting or advocating the project, helping the project through critical times, overcoming opposition, or leading coalitions". In the context of platform-based product development, the ultimate goal of leveraging product platform is to maximize long-term profits for the firm. However, platform approach may involve a greater investment both in time and money, with prolonged initial time taken to design the platform but the benefits may not be realized until future products are derived (Krishnan and Gupta, 2001). Hence, platform development serving a range of products over a longer period requires a longer performance horizon than typical single product development (Siddique, 2006). In terms of design complexity and the length of time horizon, there will be greater numbers of challenges in platform-based product development than single product development. According to Thieme et al. (2003), the champions with high technical and management skills are able to help the team to take appropriate activities and overcome obstacles. In this sense, a platform champion who is particularly effective maintaining impetus in platform-based product development and overcoming difficulties encountered should be extremely important and may help platform-based development teams achieve continuity in developing appropriate technologies and addressing specific technical difficulties.

Meyer and Dalal (2002) have shown that the continuity of management and engineering leadership increases greater reuse in non-assemble platform products. In platform-based product development, a champion is likely to be someone who knows how to utilize the platform power to its maximum and has great influence on other team members. By constantly emphasizing that the goal of the platform is overall family success, rather than a single product, champions help to instill discipline and ensure that team members design subsystems and modules which can be reused in the future. Given the complexity involved and priority differences, team members are likely to have conflicting views on how to design a subsystem. In such situations, the presence of a champion is likely to help resolve conflicts between designers, and maintain harmony by emphasizing the overall goal of platform design. Such a peacemaking role will help to overcome conflicts which in turn will lead to better product compatibility. Finally, because of the overarching importance of the platform development, the champion needs to ensure that the return on the huge investment is maximized, which requires pushing product developers to derive as many products as possible from the same platform. Summarizing these arguments, we hypothesize that:

*H7a: Existence of a champion in platform-based product development has a positive influence on the level of reusability of subsystems of platform-based products.*

*H7b: Existence of a champion in platform-based product development has a positive influence on the level of compatibility of subsystem interfaces of platform-based products.*

*H7c: Existence of a champion in platform-based product development has a positive influence on the level of extensibility of platform-based products.*

Moreover, thanks to the champion's existence, his experience gathered by solving problems of existing products provides information on how to deal with similar problems with identical solutions for successive products. Therefore, firms usually assign one key personnel from past related projects in their new projects as suggested by Takeuchi and Nonaka (1986). Similarly, this was also observed in our field studies. As explained by the principal in company B "next generation platform always needs to hold all the old functionality of the existing product platform. It causes functionality growing and growing. We need an expert to lead our team to determine what next to be built and scope new functionality constrained by marketing priority and technology. Most importantly, he may use his previous knowledge to solve the new problems by least resources, which reduces our development cost greatly". Therefore, we further hypothesize the following:

*H7d: Existence of a champion in platform-based product development is positively associated with the level of platform cost efficiency.*

### 3.3.3 Moderating effects of technologically turbulent environment in platform-based product development.

Technological turbulence refers to the inability or instability of accurately predicting the technological environment related to new product development projects (Song and Montoya-Weiss, 2001) along with high frequency of technological changes (Jaworski and Kohli, 1993). Thus, such turbulence can be defined in terms of a persons' perceived inability to understand how the external environment may evolve and whether subsequent actions taken may be successful (Bstieler, 2005). Hence, in our study, we refer to the technologically turbulent environment as the environment with perceived instability of the technology and the unpredictability of rapid change of the technology. Given the fact that the turbulent environment that originates from technologies may impact product development performance (Bstieler, 2005), as well as we found in Haurser's (2001) 5-year study, at one high technology firm, if the platform approach is not applied properly, such approach does not improve profitability, therefore consideration of technologically turbulent environment is important to the analysis in our research. Such moderating effects of technological turbulence have been studied recently in other research contexts (e.g. Song and Montoya-Weiss, 2001; Song et al., 2005a; Bstieler, 2005).

A turbulent environment brings higher uncertainty, which in turn may necessitate different degree of efforts to achieve better outcomes (Bstieler, 2005). According to the organization information processing theory, the uncertainty of a task has implications for task planning, execution, and outcomes (Tushman and Nadler, 1978). When uncertainty is high, information processing requires data acquisition and systematic analysis to reduce the uncertainty and formalized search is the principal information vehicle (Daft and Lengel, 1986). This is consistent with the contingency theory, which indicates the higher levels of technological uncertainty have greater information-processing requirements (Sherman, et al. 2005). In other words, the greater the level of uncertainty associated with the technology, the greater the amount of information needs to be processed (Sherman, et al. 2005; Tushman, 1979). When the technological environment is perceived as rapidly changing, a formalized platform-based product development process could be a good mechanism to provide sufficient data and facilitate the amount of information needed for management coordination and control. Only following a well-structured platform-based product development process step by step, engineers may make sure whether the subsystems can be used in the follow-on products properly and the interfaces can be compatible with new subsystems, and as well as how more products can be produced. Therefore, we assume that the hypothesized relationships between formalized platform-based product development process and the reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products (H4a, H4b, H4c) are contingent upon the technologically turbulent environment in which the firms experience. Moreover, the use of an established set of routines seems more important to the success of development cycle time (H4d) because it ensures the information can be accessed by the right people in a timely manner in an appropriate order and from the proper sources under highly technological turbulence. Therefore, we hypothesize the following:

*H8a: The positive relationship between formalized platform-based product development process and reusability of subsystems of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H8b: The positive relationship between formalized platform-based product development process and compatibility of subsystem interfaces of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H8c: The positive relationship between the formalized platform-based product development process and extensibility of platform-based products is stronger in a high* *technologically turbulent environment than in a low technologically turbulent environment.*

*H8d: The positive relationship between the formalized platform-based product development process and platform cycle time efficiency is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

Similarly, under a high technologically turbulent environment, design knowledge dissemination across platform-based products provides a similar mechanism in facilitating information-processing as formalized platform-based product development process. Therefore, we also assume there are moderating effects of technological-turbulent environment existing on the effects from design knowledge dissemination. Thus, we hypothesize the following:

*H9a: The positive relationship between design knowledge dissemination across a series of platform-based products and reusability of subsystems of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H9b: The positive relationship between design knowledge dissemination across a series of platform-based products and compatibility of subsystem interfaces of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H9c: The positive relationship between design knowledge dissemination across a series of platform-based products and extensibility of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

In addition, in the context of platform-based product development projects, we expect that in lowly turbulent and slowly changing technology environments, knowledge may keep steady for a certain period of time. Therefore, member changes may not cause knowledge loss to the team as much as in a high technologically turbulent environment and also may not be as hard as in a high technologically turbulent environment to fill the knowledge void. Hence, the effects caused by continuity of platform-based product development team in a low technologically turbulent environment may not be as strong as in a high technologically turbulent environment. Therefore, we further hypothesize the following:

*H10a: The positive relationship between continuity of platform-based product development team and reusability of subsystems of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H10b: The positive relationship between continuity of platform-based product development team and compatibility of subsystem interfaces of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H10c: The positive relationship between continuity of platform-based product development team and extensibility of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H10d: The positive relationship between continuity of platform-based product development team and platform cycle time efficiency is stronger in a high* *technologically turbulent environment than in a low technologically turbulent environment.*

The same reasoning can also be made to the existence of a champion in platform-based product development. In a high technologically turbulent environment, it is likely that the platform needs to be more robust in order to accommodate the many changes. The value of champions in platform-based product development largely exists in their special technical and/or management skills that may help development teams to overcome obstacles when making those changes. However, in a low technologically turbulent environment, firstly, such particular technical advantages hold by champions over other team members might not be as obvious as in a high technologically turbulent environment, due to the stability of the technology at that time. Secondly, there might be not as many technical difficulties involved in platform-based product development in a low technologically turbulent environment as in a high technologically turbulent environment. Hence, the importance of a platform champion to effectively maintain impetus in platform-based product development and overcome difficulties encountered might be lower in a low technologically turbulent environment than in a high technologically turbulent environment. So, we further hypothesize the following:

*H11a: The positive relationship between existence of a champion in platform-based product development and reusability of subsystems of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H11b: The positive relationship between existence of a champion in platform-based product development and compatibility of subsystem interfaces of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H11c: The positive relationship between existence of a champion in platform-based product development and extensibility of platform-based products is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

*H11d: The positive relationship between existence of a champion in platform-based product development and platform cost efficiency is stronger in a high technologically turbulent environment than in a low technologically turbulent environment.*

## 3.4 Summary

All the hypotheses of direct effects are presented in a conceptual model shown in Figure 3.2. To keep the figure readable, the hypotheses regarding the moderating effects are not included in this figure. But it is obvious that the hypothesized moderating effects of technologically turbulent environment which we are examining are on each path starting from the boxes in the left column (i.e. H4a ~ H7d).

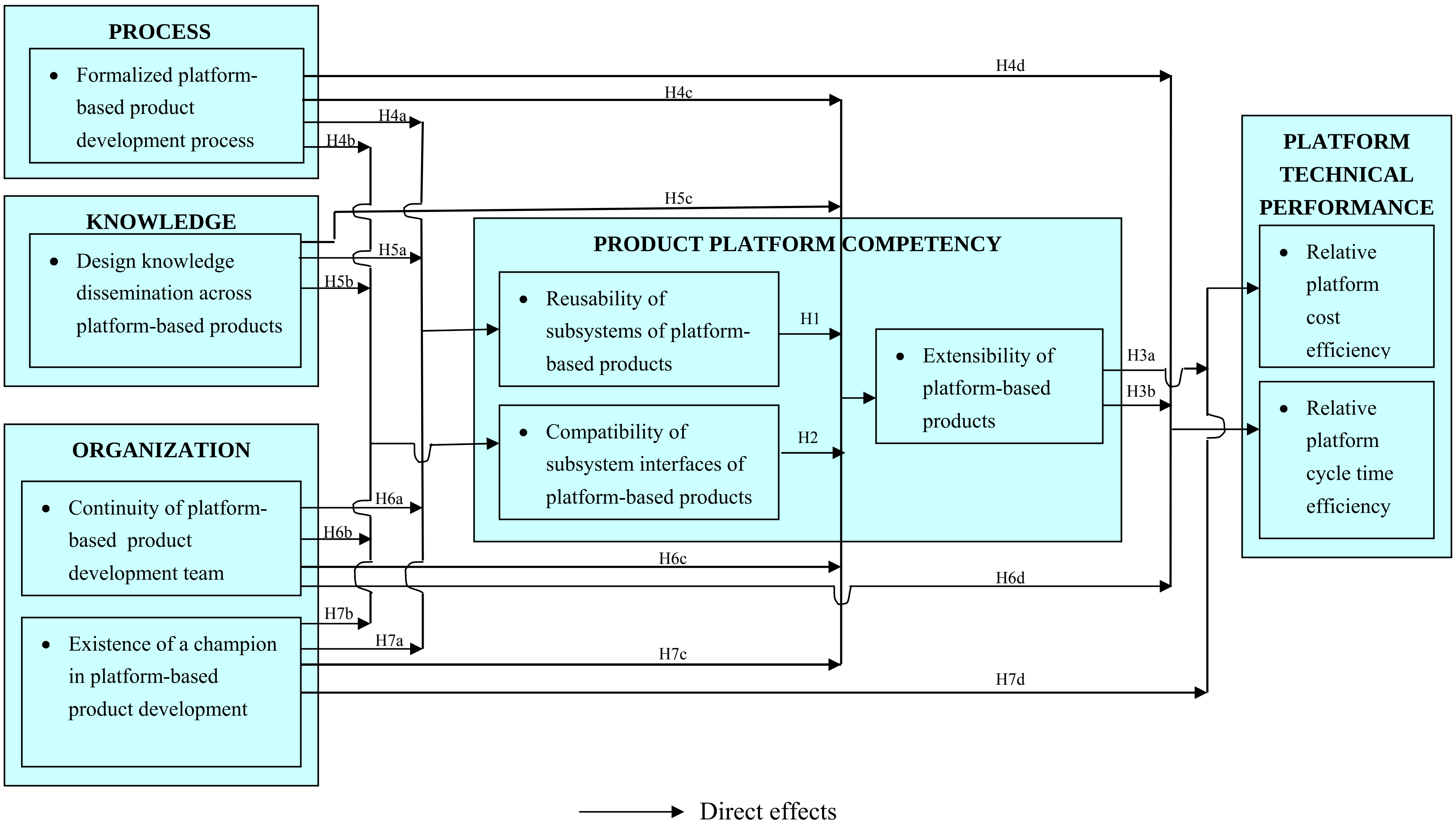



Figure 3.2 The conceptual model

# CHAPTER 4 Survey Instrument Development and Implementation

## 4.1 Introduction

In the previous chapter a set of hypotheses were developed based on the existing literature and further supported by the findings from our exploratory field studies. In this chapter we will explain the quantitative methodology adopted for testing these hypotheses. Firstly, we explain how we operationalize theoretical constructs with measurable items, and how these items are adapted from the mainstream literature or from our field studies for our research objectives. Secondly, we elaborate on the process of our questionnaire design. Lastly, we describe the sample populations we chose in our study and the procedures we took to conduct the survey.

## 4.2 Measures and questionnaire design

### 4.2.1 Measures: key model variables

The unit of analysis in our study was the derivative products based on one platform. For each of the construct we searched the literature for relevant measurements used in a new product development context, from which a pool of items was identified. When no relevant measurements were available we developed new ones specifically for this study using multiple items wherever necessary to increase reliability. For most measures we borrowed existing scales or modified existing scales and used a 7-point Likert scale in the context of platform-based product development (1 = strongly disagree with the statement to 7 = strongly agree with the statement). We now describe these measures in detail.

***Formalized platform-based product development process***

For measuring the formalized product-based product development process we used several measures developed by Rothenberger, et al. (2003) and Griffin (1997), and adapted them into the context of platform-based product development. We asked respondents to agree or disagree whether they have a well defined, well-written process in developing products from their platform, and to what extent they follow and keep track of the process. In addition, because the companies involved in our field studies claimed that they regularly check and monitor the development progress for their products derived from the platform, we developed two more measure items to measure the construct.

***Design knowledge dissemination across a series of platform-based products***

Song et al. (2007) developed a six-item scale to measure the level of knowledge dissemination within a given organization, including (1) the extent of knowledge sharing and dissemination in the organization, (2) the extent to which data on technology development are regularly disseminated in all levels of the company, (3) the extent that information about successful and unsuccessful technology development is communicated freely across all business functions, (4) the amount of cross-functional communication in the company concerning technology developments, (5) the amount of informal hall talk concerning technology development tactics or strategies, and (6) the regularity with which the company circulates documents (e.g., reports, newsletters) that describe newly created knowledge. We adapted these items for our research in the context of platform-based product development and defined the scope of such organization as the product development teams from a same platform.

***Continuity of platform-based product development team***

Following Akgun and Lynn (2002), we asked the respondents to agree or disagree whether their department managers and team members who are on the team remain on it from one product to another from the common platform. In addition, adopting the concept of team continuity from Cooper and Kleinschmidt (1993a), as well as from our field studies, we further asked the respondents whether a same team is responsible for several products and whether a same team is accountable from inception through launch for the products.

***Existence of a champion in platform-based product development***

Existence of a champion in platform-based product development was measured using five items adapted from Howell et al. (2005), to assess the degree how a champion who persists under adversity to support a series of products. These items showed a champion’s performance in the following five aspects: showing tenacity in overcoming obstacles; being involved with the product design and its implementation; knocking down barriers to the product design; persisting in the face of adversity and sticking with the objectives.

***Reusability of subsystems of platform-based products***

Following Rothenberger et al. (2003), Worren et al. (2002) and Hofer and Halman (2005), we developed five items specifically for our research to measure the reusability of subsystems and assess to what extent the platform subsystems are reused among different products derived from one common platform, such as high commonality in both requirements definition phase and product completion phase, strategic common functional module design, high degree of same functional module reuse and "on the shelf" module reuse.

***Compatibility of subsystem interfaces of platform-based products***

Similar to the reusability of subsystems of platform-based products, compatibility of subsystem interfaces is also a relatively new concept in particular in the context of survey research. Based on the relevant concepts from the extant literature, Hofer and Halman (2005), Worren et al. (2002) and Souder and Song (1997), as well as from the interviews in our field studies, we generated six measurement items to measure the degree how platform subsystem interfaces are compatible with a variety of subsystems used by different products derived from one common platform. These six items are: standardization of system layout, high degree of common interfaces, easiness of making changes, easiness of adding functions, suitability of incorporating different functions and suitability of future development.

***Extensibility of platform-based products***

Extensibility of platform-based products refers to the capacity of the platform in producing derivative products. Such capacity shows the ability to accommodate new component technologies and variations, allowing the firms to create derivative products at incremental cost relative to their initial investments in the platform itself (Meyer and Lehnerd, 1997). Therefore we examined the extensibility of platform-based products by measuring the number of products that are derived from the platform. The more products the platform can produce, the higher extensibility of products the platform shows.

***Platform cost efficiency***

The dependent construct "Platform technical performance" is divided into "platform cost efficiency" and "platform cycle time efficiency". Using perceived performance scales relative to objectives allows comparisons across firms and contexts (such as across particular industries, time horizons and economic conditions) (Song et al. 2005a). Song et al. (2005a) claimed that the managers preferred subjective to objective measures because the latter are often confidential, which is also consistent with our findings in our interviews in our field studies. The literature shows that subjective scales are widely used and that there are high correlations between objective and subjective performance measures (Song et al. 2005a).

Therefore, in our study, the platform cost efficiency was measured using three perceived items: relative costs to competitors' costs (adapted from Song and Parry, 1997), relative costs to projected costs (adapted from Song and Parry, 1997) and average derivative product costs relative to initial product costs based on the same platform (adapted from Meyer et al., 1997).

***Platform cycle time efficiency***

Similarly, the platform cycle time efficiency was measured using three perceived items: relative cycle time to competitors' cycle time (adapted from Song and Parry, 1997), relative cycle time to projected cycle time (adapted from Song and Parry, 1997) and average derivative product development cycle time relative to initial product development cycle time based on the same platform (adapted from Meyer et al., 1997).

### 4.2.2 Measures: moderating variables

***Technologically turbulent environment***

We used existing scales from Song et al. (2005a) to measure the degree of technologically turbulent environment as follows:

- The technology in our industry is changing rapidly
- Technological changes provide big opportunities in our industry
- It is very difficult to forecast where the technology in our industry will be in the next 2-3 years

∗ Technological development in our industry is rather major.

### 4.2.3 Measures: control variables

Following existing literature, three control variables were introduced, i.e. division size (Chai and Xin, 2006), sales (Bij et al. 2003) and R&D expenditure ratio (Graves, 1988). Division size was measured by the number of full-time employees in the division/strategic business unit. Sales was measured by the annual sales of the business unit last year, while R&D expenditure ratio was taken as R&D expenditure as a percentage of sales.

Previous studies indicate that organizational size—number of employees—affects firms' new product development activities and performance (Kim et al., 2005). The logic is that large firms with larger number of employees and/or volumes of sales may have more resources to expand their product lines, hence having the advantages in their product platform capability to produce more products. Also, the companies which indicate more human resources and/or R&D expenditure ratio may have stronger impact on the time and cost occurred in their product development.

### 4.2.4 Summary of survey measures

All the measurements are summarized in Table 4.1. As suggested by Churchill (1979), the domain of each construct was clearly defined in terms of what would be included, followed by measurement items, its corresponding code, reference and original source as shown in Table 4.1.

Table 4.1 Summary of definitions of the variables and corresponding measurement items, code with the original source

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Formalized platform-based product development process | The degree to which a complete process is well defined and implemented to develop products based on one common platform | • We have a well defined development process for creating products from this platform | FOR1 | Adapted from Rothenberger, et al. (2003) | We have a valuable process for certifying reused software components. |
| | | • There is a well written document of the process that guides our engineers to develop products from this platform | FOR2 | Adapted from Griffin (1997) | Having and following a well-documented product development process |
| | | • We regularly check the development progress of our products derived from this platform in a time base | FOR3 | Field study | N/A |
| | | • We monitor the development progress of our products derived from this platform using standard procedures | FOR4 | Field study | N/A |
| | | • We do an exceptionally good job in keeping track of the development progress of derivative products from this platform | FOR5 | Adapted from Rothenberger, et al. (2003) | Our configuration management system does an exceptionally job in keeping track of the projects, which use each reusable software component; |
| | | • Our engineers closely follow a process to develop products from this platform | FOR6 | Adapted from Rothenberger, et al. (2003) | Software developers and maintainers precisely follow a software reuse process, which is defined and integrated with the organization's software development process. |
| | | | | | |
| Design knowledge dissemination across a series of platform-based products | The degree to which the design knowledge exchange among platform-based product development teams | • The level of knowledge sharing and disseminating is high among our different product development teams from this common platform | DES1 | Adapted from Song et al. (2007) | The level of knowledge sharing and disseminating is high in this organization. |
| | | • There are a lot of informal "hall talks" concerning our technology development tactics or strategies among our different product development teams from this common platform. | DES2 | Adapted from Song et al. (2007) | There are a lot of informal "hall talk" concerning our technology development tactics or strategies |

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Design knowledge dissemination across a series of platform-based products | The degree to which the design knowledge exchange among platform-based product development teams | • Data on technology development are disseminated at all levels among our different product development teams from this common platform | DES3 | Adapted from Song et al. (2007) | Data on technology development are disseminated at all levels in our company on a regular basis |
| | | • Our different product development teams from this common platform periodically circulate documents (e.g. reports, newsletters) that provided new information and/or knowledge | DES4 | Adapted from Song et al. (2007) | Our company periodically circulates documents (e.g., reports, newsletters) that provide new knowledge created |
| | | • We freely communicate information internally about our **successful** technology development across all the products derived from this common platform | DES5 | Adapted from Song et al. (2007) | We freely communicate information about our successful and unsuccessful technology development across all business functions |
| | | • We freely communicate information internally about our **unsuccessful** technology development across all the products derived from this common platform | DES6 | Adapted from Song et al. (2007) | We freely communicate information about our successful and unsuccessful technology development across all business functions |
| | | | | | |
| Continuity of platform-based product development team | The degree to which the development team continues to work together for developing derivative products from the same platform | • A same team was accountable from inception through launch for a series of products derived from this platform | CON1 | Field study | N/A |
| | | • A same team was responsible from the beginning to the end for several products derived from this platform | CON2 | Adapted from Cooper and Kleinschmidt (1993a) | Team carried project from beginning to end -- no hand offs |
| | | • Department managers who were on the team remained on it from one product to another from this common platform | CON3 | Adapted from Akgun and Lynn (2002) for both CON3 & CON4 | Department managers who were on the team remained on it from pre-prototype through launch; |
| | | • Team members who were on the team remained on it from one product to another from this common platform | CON4 | | Team members who were on the team remained on it from pre-prototype through launch |

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Existence of a champion in platform-based product development | The degree to which there is a champion who persists under adversity to support a series of platform-based product development | • There was a champion who showed tenacity in overcoming obstacles in our product development from this platform. | CHA1 | Adapted from Howell et al. (2005) | Shows tenacity in overcoming obstacles |
| | | • There was a champion who continued to be involved with the design until it was implemented in our product development from this platform. | CHA2 | Adapted from Howell et al. (2005) | Continues to be involved with the innovation until it is implemented |
| | | • There was a champion who knocked down barriers to the design in our product development from this platform. | CHA3 | Adapted from Howell et al. (2005) | Knocks down barriers to the innovation |
| | | • There was a champion who persisted in the face of adversity in our product development from this platform. | CHA4 | Adapted from Howell et al. (2005) | Persists in the face of adversity |
| | | • There was a champion who stuck with the objectives despite experiencing negative outcomes in our product development from this platform. | CHA5 | Adapted from Howell et al. (2005) | Stick with it |
| | | | | | |
| Reusability of subsystems of platform-based products | To what extent the platform subsystems are reused among the different products derived from one common platform | • After the new product requirements were defined, we realize high commonality with the functional modules that were used by previous products | REU1 | Adapted from Rothenberger et al. (2003) | During (after) the project requirements phase we realized high commonality with the requirements of previous project(s); |
| | | • After the new product design was completed, we realize high commonality with the functional modules that were used by previous products | REU2 | Adapted from Rothenberger et al. (2003) | During (after) the project design phase we realized high commonality with the design of previous project(s); |

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Reusability of subsystems of platform-based products | To what extent the platform subsystems are reused among the different products derived from one common platform | • We usually follow a strategy to design common functional modules to be used in several products derived from this platform | REU3 | Field study | N/A |
| | | • We reuse a high degree of same functional modules in different products derived from this common platform | REU4 | Adapted from Worren et al. (2002) | The degree of component carry-over |
| | | • We try our best to reuse "on the shelf" functional modules in different products from this platform wherever possible | REU5 | Adapted from Hofer and Halman (2005) | The layout platform is a pre-requisite for building systems on existing elements (re-usability) |
| | | | | | |
| Compatibility of subsystem interfaces of platform-based products | To what extent the platform interfaces are compatible with a variety of subsystems used by the different products derived from one common platform | • There is a high degree of standardized system layout of our product architecture from this common platform | COM1 | Adapted from Hofer and Halman (2005) | The standardized layout forms a stable basis for the development and realization of the entire product family |
| | | • There is a high degree of common interfaces among different products derived from this common platform | COM2 | Field study | N/A |
| | | • It is quite easy to make changes in modules without redesigning other parts in the existing products from this common platform | COM3 | Adapted from Worren et al. (2002) | For our main product(s), we can make changes in key components without redesigning others. |
| | | • It is quite easy to add new functional modules without changing other parts to develop new derivative products from this common platform | COM4 | Field study | N/A |

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Compatibility of subsystem interfaces of platform-based products | To what extent the platform interfaces are compatible with a variety of subsystems used by the different products derived from one common platform | • The interfaces of our existing product architecture from this platform are compatible with many different functional modules<br>• The interfaces of our existing product architecture from this platform are suitable for future derivative products | COM5<br><br>COM6 | Souder and Song (1997)<br><br>Souder and Song (1997) | Product functioned in many different situations<br><br>Product was suitable for many applications |
| | | | | | |
| Extensibility of platform-based products | Capacity of product platform of accommodating the number of products | • Number of products that have been derived and commercialized from this platform | EXT | N/A | N/A |
| | | | | | |
| Platform cost efficiency | Platform cost efficiency—The degree to which the average R&D costs of the derivative products from this platform is | • Compared to our competitors, the average R&D costs of all the products from this platform was far less than our competitor's costs | COST1 | Adapted from Song and Parry (1997); | Relative to competing products, how successful was this product in terms of sales? (0 = Far less than the competing products; 10 = Far exceeded the competing products) |

| Key Model Variables | Definition | Items | Code | Reference | Original Source |
|---|---|---|---|---|---|
| Platform cost efficiency | Platform cost efficiency—The degree to which the average R&D costs of the derivative products from this platform is | • Compared to our original projected costs, the average R&D costs of all the products from this platform was far less than our projected costs<br>• Compared to the R&D cost of the first product from this platform, the average R&D costs of the follow-on derivative products from this platform was far less than the first product | COST2<br><br>COST3 | Adapted from Song and Parry (1997);<br><br>Adapted from Meyer, Tertzakian and Utterback (1997) | Relative to your firm's objectives for this product, how successful was this product in terms of sales? (0 = Far less than the objectives; 10 = Far exceeded the objectives )<br>The average of the R&D costs associated with developing all the derivative products of a platform version divided by the R&D costs of developing that version of the platform. |
| | | | | | |
| Platform cycle time efficiency | Platform cycle time efficiency—The degree to which the average development cycle time of the derivative products from this platform is | • Compared to our competitors, the average development cycle time of all the products from this platform was far shorter than our competitor's cycle time<br>• Compared to our original planned cycle time, the average development cycle time of all the products from this platform was far shorter than our planned cycle time<br>• Compared to the development cycle time of the first product from this platform, the average development cycle time of the follow-on derivative products from this platform was far shorter than the first product | TIME1<br><br>TIME2<br><br>TIME3 | Adapted from Song and Parry (1997);<br><br>Adapted from Song and Parry (1997);<br><br>Adapted from Meyer, Tertzakian and Utterback (1997) | Relative to competing products, how successful was this product in terms of sales? (0 = Far less than the competing products; 10 = Far exceeded the competing products).<br><br>Relative to your firm's objectives for this product, how successful was this product in terms of sales? (0 = Far less than the objectives; 10 = Far exceeded the objectives )<br><br>The average of the R&D cycle time associated with developing all the derivative products of a platform version divided by the R&D cycle time of developing that version of the platform. |

| **Moderating Variables** | **Definition** | **Items** | **Code** | **Literature reference** | **Original Source** |
|---|---|---|---|---|---|
| Technologically turbulent environment | The inability or instability of accurately predicting the technological environment related to new product development, along with high frequency of technological changes | • The technology in our industry is changing rapidly<br>• Technological changes provide big opportunities in our industry<br>• It is very difficult to forecast where the technology in our industry will be in the next 2-3 years<br>• Technological development in our industry is a major part of our products | TEC1<br>TEC2<br>TEC3<br>TEC4 | Adapted from Song et al. (2005a);<br>Adapted from Song et al. (2005a)<br>Adapted from Song et al. (2005a);<br>Adapted from Song et al. (2005a) | The technology in our industry is changing rapidly<br>Technological changes provide big opportunities in our industry<br>It is very difficult to forecast where the technology in our industry will be in the next 2-3 years<br>Technological developments in our industry are rather minor (R) |

| **Control Variables** | **Definition** | **Items** | **Code** | **Literature reference** | **Original Source** |
|---|---|---|---|---|---|
| Division Size | Number of full-time employees | • Number of full-time employees in your division/strategic business unit | EMPLOY | Chai and Xin (2006) | Number of full-time employees in your company now is ____ |
| R&D expenditure ratio | R&D expenditure as a percentage of sales | • R&D expenditure as a percentage of sales | RATIO | Graves (1988) | R&D spending as ratio to sales |
| Sales | Last year sales | • The annual sales of your division/strategic business unit last year (approximately) | SALES | Bij et al. (2003) | The size of an SBU's sales revenues in its principal served market segment in relation to those of its largest competitor (0-10 scale) |

### 4.2.5 Questionnaire design

Following Tull and Hawkins (1987) and Forza (2002), question wording, response format and physical characteristics of the questionnaire were carefully considered in our questionnaire design. For question format and wording, we wanted to make sure that our questionnaire could be easily read and understood, as well as encouraged the respondents to give more information in a shorter time. As such, except two semi-open questions, all the other questions were close-ended both in our pre-survey and final survey questionnaire (See Appendix B and Appendix C). In order to increase the reliability and validity of the answers to our questions, some question wording is designed in a reversed order as suggested by Dillman (1978).

### 4.2.6 Pre-test of the questionnaire

To examine the accurate wording, conceptual validity of the items and to estimate the time to complete the questionnaire, a pre-test was conducted. Preliminary draft of the questionnaire was sent to a panel of academics and practitioners to check for the ease of use and understanding of the measurement items. These reviews helped to refine a number of the items. The revised questionnaire was then submitted to seven experienced R&D managers and engineers for the clarity and appropriateness in Singapore. Based on the feedback obtained from the participants, some items were eliminated, and others were modified. Prior to the large-scale survey, the final research instrument was subjected to additional pretesting in the United States to check for the ease of use and understanding of the measurement items. These pretests were conducted with four executives in a software company and an automotive company. The executives were asked to complete the survey and raise any questions. At this stage, the pretest resulted in only minor refinement of a few of measurement items. The survey was finalized using the results of pretests.

## 4.3 Survey implementation

Mail survey method is adopted in current study. Our sampling frame consists of 1000 randomly selected firms in U.S. from all nonservice firms listed in the *World Business Directory* in the following industries: Industrial Machinery & Equipment; Electronic

Parts & Equipment; Communications Equipment; Software Product; Computers & Peripheral Equipment; Motor Vehicles & Motor Vehicle Parts; Chemicals & Allied Products; Medical, Dental & Hospital Equipment.

We sent a pre-survey letter to all 1000 firms requesting pre-approval of participation and assessing suitability of the firm (to check if they have had developed and commercialized a platform product in the past five years), as shown in Appendix A. The pre-survey stated the purpose of this study and consisted of the following three questions: Have you had developed and commercialized a platform product in the past five years? Do your product platform designs enable you to accommodate several generations of products, which are regarded as one product family? Are your product platform designs drawn to accommodate future generations of products, which will be regarded as one product family? 387 firms agreed to participate and provided a contact person. 67 companies declined to participate or did not have product platforms. 63 letters were returned due to invalid contact person or addresses. 483 companies did not respond.

In administering the final survey (see Appendix B), we followed the total design method for survey research (Dillman, 1978). The first mailing packet included a personalized letter, the survey, a priority prepaid envelope with an individually typed returned address label, and a list of research reports available for participants. The package was sent by priority mail to 387 firms which agree to participate and 483 non-responding firms from the pre-survey. We asked the contact person to select one of the major product platforms currently in the company, from which several products have been derived and commercialized. This product platform should be considered a representative of the company's platforms. The contact person was also asked to distribute the questionnaire to the R&D-manager or the person in the company responsible for leading the development of the selected platform.

To increase the response rate, we sent four follow-up mailings to the companies. One week after the mailing, we sent a follow-up letter. Two weeks after the first follow-up, we sent a second package with same content as the first package to all non-responding companies. After two additional follow-up letters, we received completed questionnaires from 256 firms, representing a response rate of 29.4% (256/870).

## 4.4 Summary

Measures of each construct were discussed in this chapter. While the measures were drawn from literature wherever possible, a number of items were developed specifically for this survey. The procedures of survey implementation and administration at our targeted sample were also described in details. After the data collection, preliminary analysis was done, followed by measurement and structural model analysis, and moderating effect analysis, which will be discussed in next chapter.

# CHAPTER 5 Data Analysis and Results

## 5.1 Introduction

This chapter presents the results and data analysis of the survey conducted. A descriptive analysis is conducted for a better understanding of the profiles of sampling populations, as well as to assess the validity of the data set. The measurement model is then assessed through both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). With a high quality of measurement model achieved, we test the hypotheses regarding direct effect in the structural model through structural equation modeling (SEM), because "structural equation modeling provides researchers with a comprehensive method for the quantification and testing of theories" (Raykov and Marcoulides, 2000, pp.1). Finally, hypotheses regarding the moderating effects are examined.

## 5.2 Descriptive analysis

Out of 870 copies of questionnaires we sent out, 256 were returned, resulting in a 29.4% response rate. We did double entry of the data—two people enter the same data and then we used a program to compare the two data files to make sure of the accuracy of the data entries.

After examining the data, we found that there were total 14 companies with one product from the platform, which we required at least two products in our study. Therefore, we decided to delete these 14 samples and the useable data thus dropped to 242 remained in our data analysis. Our total sample size were 242 firms finally with complete data, which were satisfied with the request of structural equation modeling as in general, a sample size of approximately 200 for models of moderate complexity is recommended for structural equation modeling (Boomsma, 1983; Kelloway, 1998).

As suggested by Leech et al. (2005), we checked for errors and assumptions with the both the ordinal and scale variables. First, we ran descriptive statistics for our scale variables and the output is shown in Table 5.1. The details of unit of measures for each measurement item are illustrated in the Appendix B Final Survey Questionnaire. Sales (in thousand $) were calculated as the natural logarithm of the business unit's total sales over the last year. We used the natural logarithm form to reduce heteroscedasticity according to the suggestion of Kerlinger (1973).

***Checking data for errors using the Descriptive Statistics***

Following the procedures advised by (Leech et al. 2005), we checked that all the means of our variables were within the ranges we expected. We also saw that the Minimum and Maximum were within the appropriate range of each variable. Finally, in the N column the Ns were what we were expecting as well. Hence, we concluded that there were no errors found in our data set.

***Checking data for assumptions using the Descriptive Statistics***

The main assumption that we checked from Descriptive Statistics Output is normality. This is because Structural Equation Modeling requires a multivariate normality in the data and is sensitive to the distributional characteristics of the data, particularly a strong skewness (Hair et al. 1998). According to Leech et al. (2005), "Skewness refers to the lack of symmetry in a frequency distribution. Distributions with a long tail to the right have a positive skew and those with a long tail on the left have a negative skew" (pp.29).

Table 5.1 Descriptive statistics

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness |
|---|---|---|---|---|---|---|
| EXT | 242 | 2 | 15 | 5.31 | 3.232 | .728 |
| REU1 | 242 | 1 | 7 | 4.26 | 1.646 | -.425 |
| REU2 | 242 | 1 | 7 | 4.37 | 1.724 | -.445 |
| REU3 | 242 | 1 | 7 | 4.13 | 1.671 | -.377 |
| REU4 | 242 | 1 | 7 | 4.28 | 1.658 | -.415 |
| REU5 | 242 | 1 | 7 | 3.99 | 1.703 | -.133 |
| COM1 | 242 | 1 | 7 | 4.56 | 1.603 | -.442 |
| COM2 | 242 | 1 | 7 | 4.55 | 1.660 | -.390 |
| COM3 | 242 | 1 | 7 | 4.37 | 1.584 | -.180 |
| COM4 | 242 | 1 | 7 | 4.69 | 1.718 | -.448 |
| COM5 | 242 | 1 | 7 | 4.67 | 1.758 | -.536 |
| COM6 | 242 | 1 | 7 | 4.90 | 1.488 | -.659 |
| FOR1 | 242 | 1 | 7 | 4.96 | 1.509 | -.682 |
| FOR2 | 242 | 1 | 7 | 4.62 | 1.558 | -.392 |
| FOR3 | 242 | 1 | 7 | 4.07 | 1.723 | -.105 |
| FOR4 | 242 | 1 | 7 | 5.23 | 1.444 | -.937 |
| FOR5 | 242 | 1 | 7 | 4.56 | 1.677 | -.413 |
| FOR6 | 242 | 1 | 7 | 4.81 | 1.399 | -.511 |
| CON1 | 242 | 1 | 7 | 3.79 | 1.780 | .062 |
| CON2 | 242 | 1 | 7 | 4.17 | 1.713 | -.195 |
| CON3 | 242 | 1 | 7 | 4.36 | 1.707 | -.237 |
| CON4 | 242 | 1 | 7 | 4.17 | 1.747 | -.143 |
| DES1 | 242 | 1 | 7 | 4.80 | 1.473 | -.407 |
| DES2 | 242 | 1 | 7 | 4.92 | 1.252 | -.350 |
| DES3 | 242 | 1 | 7 | 5.00 | 1.484 | -.614 |
| DES4 | 242 | 1 | 7 | 4.52 | 1.843 | -.175 |
| DES5 | 242 | 1 | 7 | 4.21 | 1.573 | -.282 |
| DES6 | 242 | 1 | 7 | 5.24 | 1.431 | -.875 |
| CHA1 | 242 | 1 | 7 | 4.85 | 1.428 | -.642 |
| CHA2 | 242 | 1 | 7 | 4.13 | 1.679 | -.353 |
| CHA3 | 242 | 1 | 7 | 4.51 | 1.615 | -.218 |
| CHA4 | 242 | 1 | 7 | 4.26 | 1.673 | -.381 |
| CHA5 | 242 | 1 | 7 | 5.10 | 1.776 | -.861 |
| TEC1 | 242 | 1 | 7 | 5.09 | 1.539 | -.993 |
| TEC2 | 242 | 1 | 7 | 4.64 | 1.619 | -.594 |
| TEC3 | 242 | 1 | 7 | 4.13 | 1.752 | -.204 |
| TEC4 | 242 | 1 | 7 | 4.14 | 1.866 | -.210 |
| COST1 | 242 | 1 | 7 | 4.94 | 1.691 | -.666 |
| COST2 | 242 | 1 | 7 | 5.51 | 1.470 | -1.242 |
| COST3 | 242 | 1 | 7 | 5.02 | 1.636 | -.882 |
| TIME1 | 242 | 1 | 7 | 5.00 | 1.882 | -.674 |
| TIME2 | 242 | 1 | 7 | 5.10 | 2.080 | -.825 |
| TIME3 | 242 | 1 | 7 | 4.96 | 1.915 | -.677 |
| EMPLOY | 242 | 1 | 4 | 3.09 | .900 | -.551 |
| RATIO | 242 | 1 | 4 | 2.02 | 1.044 | .664 |
| SALES | 242 | 6.53 | 14.19 | 10.14 | 2.909 | -.085 |
| Valid N (listwise) | 242 | | | | | |

A simpler guideline is that if the skewness is between -1 and 1, the variable is at least approximately normal. (Leech et al., 2005). For the variables that were labeled scale, we saw that from the Table 5.1, most of these variables have skewness values between -1 and +1, but COST2 at -1.242 is slightly skewed. As it was only a little above the criteria, it was remained for further analysis.

Next, we computed Frequencies for the ordinal variable of industry distribution in our research and the complete set of 242 companies that participated and the industries represented are shown in Table 5.2.

Table 5.2 Industry distribution

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| 1 | Industrial Machinery & Equipment | 12 | 5.0 | 5.0 | 5.0 |
| 2 | Electronic Parts and Equipment | 33 | 13.6 | 13.6 | 18.6 |
| 3 | Communications Equipment | 22 | 9.1 | 9.1 | 27.7 |
| 4 | Software-related Product | 50 | 20.7 | 20.7 | 48.3 |
| 5 | Computer & Peripheral Equipment | 64 | 26.4 | 26.4 | 74.8 |
| 6 | Motor Vehicles & Motor Vehicle Parts | 12 | 5.0 | 5.0 | 79.8 |
| 7 | Chemicals & Allied Products | 8 | 3.3 | 3.3 | 83.1 |
| 8 | Medical, Dental & Hospital Equipment | 35 | 14.5 | 14.5 | 97.5 |
| 9 | Others | 6 | 2.5 | 2.5 | 100.0 |
| | Total | 242 | 100.0 | 100.0 | |

It is clear that the largest groups of respondents are from Computer-related products, Software-related Products, Medical-related Products and Electronic Products, which account for over 75% of total respondents. This is consistent with what we are expecting, because more of these products take the modular architecture and more likely will leverage platform strategy.

## 5.3 Measurement models

Following Paladino (2007), we firstly employed two more statistical tests before factor analysis: Kaiser-Meyer-Olkin (KMO) statistic and Barlett's Test of Sphericity. The results are shown in Table 5.3.

Table 5.3 KMO and Bartlett's test

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .852 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 6649.949 |
| | df | 861 |
| | Sig. | .000 |

The KMO test tells whether or not enough items are predicted by every factor (Leech et al. 2005). The KMO measure should be greater than .70 and values between 0.8 and 0.9 are desirable (Hutcheson and Sofroniou, 1999). The overall KMO of our sample is .852, which is within the desired range. Furthermore, the Bartlett's measure tests the null hypothesis that the original correlation matrix is an identity matrix. It should be significant to indicate the variables are correlated highly enough to give a reasonable basis for factor analysis (Leech et al. 2005). Our test has a significant value of .000, which shows the original matrix is not an identity matrix. Thus, both the KMO and Bartlett's Test of Sphericity indicated that factor analysis was an appropriate technique to be used in our study.

Prior to testing our hypotheses, all the multi-item measures were subjected to a commonly used validation process to assess their unidimensionality, internal consistency, convergent validity and discriminant validity (Gerbing and Anderson, 1988; Bagozzi et al. 1991). Following the recommendations of previous research, to obtain the unidimensionality, measurement items were subjected to exploratory factor analysis (EFA) with results providing support for the unidimensionality of constructs (Ahire and Devaraj, 2001). And confirmatory factor analysis (CFA) was used to verify the internal consistency, convergent validity and discriminant validity of the measures (Fornell and Larcker, 1981; Bagozzi et al., 1991). Therefore, an exploratory factor analysis (EFA) was carried out using SPSS 15.0 first. Next, using LISREL 8.7, a two-step approach was adopted as advised by Gerbing and Anderson (1988) to assess a measurement model by confirmatory factor analysis (CFA) prior to the estimation of a structure model. The moderator hypotheses were tested after the main effects had been assessed. In sum, the empirical analysis was done in the following three stages: a measurement model tested through EFA and CFA, a path model containing the main effects, and models testing the moderator hypotheses.

### 5.3.1 Exploratory factor analysis

Before we performed EFA, for these multi-items scales, following Langerrak et al. (2004) and Barczak et al. (2007), we first computed the interitem correlations and item-to total correlations for each item, taking one scale at a time. Items for which these correlations were not significant ($p<.01$) were eliminated. At this step, three items DES2, DES4 and DES 6 were eliminated. Next, we employed exploratory factor analysis to determine if the construct scale actually represents more than one distinct dimension and examine the unidimensionality (Ahire and Devaraj, 2001). Unidimensionality is defined as the extent to which observed indicators are strongly associated with each other and represent a single concept, which is a necessary condition for reliability analysis and construct validation (Hattie, 1985). In order to assess the unidimensionality, exploratory factor analysis can be conducted with varimax rotation on the construct scale (Schwab, 1980). Most researchers use 0.4 or 0.3 as a threshold in the evaluation of the factor loadings to determine if the scale has appropriate unidimensionality. Therefore, following the practices of Langerak et al. (2004) and Kleinschmidt et al. (2007), we conducted exploratory factor analysis using varimax rotation and an eigenvalue of 1 as the cut-off point to determine item loadings, and to eliminate items that do not load cleanly onto any factors. The factor analysis resulted in nine factors as expected. Two more items CHA1 and FOR6 were subsequently dropped because they failed to load clearly. All together, 5 items (DES2, DES4, DES6, CHA1 and FOR6) were trimmed from the initial 42 items. The final results after the trimming exercise show unidimensionality of each scale with eigenvalue greater than 1 and all items loading on the appropriate respective factor at greater than .60, as shown in the factor loadings in Table 5.4. This provides support for the unidimensionality of constructs (Ahire and Devaraj, 2001).

## Table 5.4 Factor loadings with varimax rotation

| | Factor Loadings* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Items | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
| COM3 | **.785** | .105 | .139 | .144 | -.086 | -.062 | -.001 | .042 | .117 |
| COM2 | **.727** | .024 | .374 | .103 | .082 | .123 | .247 | .102 | .134 |
| COM4 | **.725** | -.027 | .198 | .060 | .003 | .109 | .177 | -.009 | .214 |
| COM1 | **.725** | .099 | .179 | .049 | .274 | .131 | .173 | .129 | .026 |
| COM6 | **.644** | .151 | .030 | .256 | .179 | .137 | -.183 | .123 | .196 |
| COM5 | **.604** | .120 | .080 | .154 | .358 | .321 | .193 | .075 | .132 |
| FOR1 | .036 | **.849** | .147 | .048 | .100 | .025 | .146 | .064 | .020 |
| FOR2 | .120 | **.827** | -.034 | .118 | .118 | .009 | .190 | .145 | .102 |
| FOR3 | .083 | **.720** | -.142 | .185 | .061 | .235 | .174 | .114 | .090 |
| FOR5 | -.004 | **.706** | .284 | .084 | .172 | .066 | .156 | .125 | .046 |
| FOR4 | .124 | **.674** | -.138 | .063 | -.095 | .121 | .258 | .110 | .110 |
| CON1 | .198 | -.007 | **.806** | .202 | .022 | .039 | .093 | .049 | .091 |
| CON4 | .176 | .078 | **.788** | .091 | .104 | .195 | .154 | .094 | .157 |
| CON3 | .223 | .029 | **.749** | .205 | .186 | .054 | .034 | .180 | .087 |
| CON2 | .145 | -.033 | **.732** | .201 | .231 | .077 | -.077 | .141 | .061 |
| REU4 | .036 | .134 | .082 | **.831** | .098 | .029 | .166 | .053 | .090 |
| REU5 | .144 | .137 | .138 | **.758** | .151 | .094 | .201 | -.012 | .170 |
| REU3 | .180 | .099 | .361 | **.664** | .174 | .040 | .009 | -.092 | .097 |
| REU1 | .300 | .119 | .280 | **.643** | .231 | .097 | .213 | -.033 | -.003 |
| REU2 | .099 | .046 | .160 | **.609** | .203 | .249 | .256 | .041 | -.145 |
| CHA4 | .238 | .137 | .235 | .220 | **.801** | .057 | .087 | .033 | .107 |
| CHA2 | .236 | .165 | .095 | .306 | **.764** | .076 | .083 | -.053 | .069 |
| CHA3 | .149 | .193 | .377 | .261 | **.687** | .127 | .045 | -.053 | .001 |
| CHA5 | -.117 | -.057 | .031 | .039 | **.646** | .246 | .252 | .061 | .096 |
| COST2 | .076 | .022 | .075 | .111 | .128 | **.882** | -.012 | -.063 | .053 |
| COST3 | .105 | .197 | .110 | .062 | .057 | **.842** | .002 | -.008 | .130 |
| COST1 | .226 | .143 | .149 | .141 | .220 | **.762** | .177 | -.059 | .092 |
| TEC2 | .040 | .383 | .022 | .109 | .148 | .024 | **.747** | .019 | .125 |
| TEC4 | .171 | .198 | .171 | .228 | .105 | .003 | **.671** | -.035 | .113 |
| TEC1 | .059 | .254 | -.020 | .176 | .218 | .156 | **.656** | .112 | .004 |
| TEC3 | .174 | .229 | .069 | .211 | .007 | -.006 | **.632** | .079 | .171 |
| TIME1 | .042 | .155 | .104 | .088 | .009 | -.028 | .054 | **.894** | -.054 |
| TIME3 | .078 | .079 | .076 | -.058 | .086 | -.019 | .022 | **.872** | .010 |
| TIME2 | .132 | .196 | .159 | -.039 | -.088 | -.055 | .054 | **.740** | .040 |
| DES1 | .155 | .044 | -.013 | .268 | .081 | .136 | .088 | .122 | **.770** |
| DES3 | .223 | .125 | .183 | .044 | .074 | .097 | .113 | -.039 | **.747** |
| DES5 | .161 | .121 | .163 | -.073 | .064 | .040 | .115 | -.070 | **.679** |

* Items identified as nine factors: F1= Compatibility of subsystem interfaces of platform-based products; F2= Formalized platform-based product development process; F3= Continuity of platform-based product development team; F4= Reusability of subsystems of platform-based products; F5= Existence of a champion in platform-based product development; F6= Platform cost efficiency; F7= Technologically turbulent environment; F8= Platform cycle time efficiency; F9= Design knowledge dissemination across a series of platform-based products.
Note: black numbers indicate items that load highly for each of the nine factors

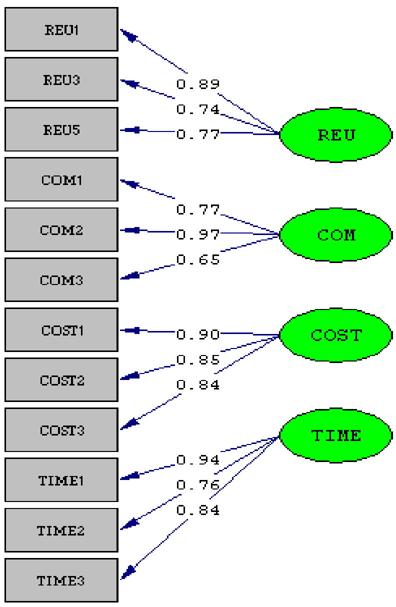
### 5.3.2 Confirmatory factor analysis

To assess the reliability, convergent and discriminant validity of the measurement model, the measures were subject to a further purification process as advised by Churchill (1979) and Gerbing and Anderson (1988). For the multiple-item scales, a confirmatory factor analysis (CFA) was performed by applying maximum likelihood estimates in LISREL 8.7 (Joreskog and Sorbom, 1993). The covariance matrix of the items was used as input.

Due to the small sample size relative to the number of items, one measurement model encompassing all elements of the model would violate the recommendation advised by Bentler and Chou (1987) and Hair et al. (1988) that a five-to-one ratio of sample size to free parameters should be followed to yield appropriate significance tests. Therefore, following the recommendations of Ayers et al. (1997) and (Pillai et al, 1999), the scales were assessed in two phases. One CFA was performed for dependent and the mediating variables, and a separate CFA for the independent variables. Such an approach was also applied in previous studies by Song et al. (2005b), Kim et al. (2005) and Paladino (2007).

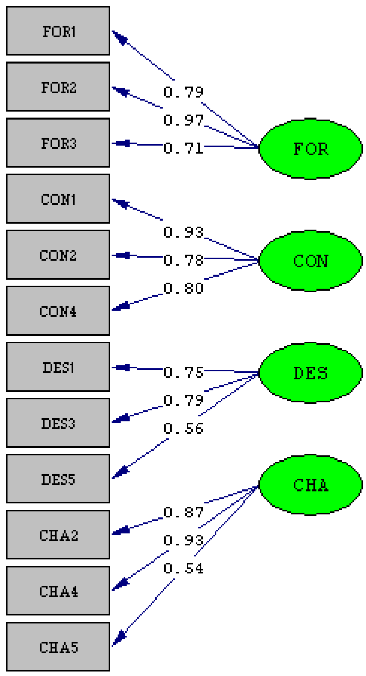
Goodness of fit tests determines if the model being tested should be accepted or rejected. If the model is accepted, we will then go on to interpret the path coefficients in the model because if the goodness of fit measures is poor, the "significant" path coefficients are not meaningful (Hair et al. 1998). In this study, we examined the following fit indices recommended by Kline (1998), such as Chi-square ($\chi 2$), Normed fit index (NFI), Comparative fit index (CFI), Goodness-of-fit index (GFI), Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR). For NFI, CFI and GFI, by convention, the scores of .90 or higher are considered evidence of good fit (Cuttance, 1987) and the SRMR values of 0.05 or lower are interpreted as indicating a good fit to the data (Kelloway, 1998). In addition, Joreskog (1969) proposed using the ratio of the $\chi 2$ for a model divided by the model's degrees of freedom ($\chi 2$/df) as a more appropriate measure of fit than the $\chi 2$ if the sample size is large. Carmines and McIver (1981) suggested that a ratio of two or three is adequate. LISREL also reports RMSEA, which is based on the analysis of residuals, with smaller values indicating a better fit to the data. Steiger (1990) suggests that values below 0.10 indicate a good fit to the data.

During the CFAs, we reviewed each construct and deleted items that loaded on multiple constructs or had low item-to-construct loadings. After deletion of each item, the CFA is carried out again. If the indices still don’t fit, we look at the next item for deletion. We repeat the process until the fit indices have reached the acceptable values. In addition, if they correlate strongly with another item, they are actually measuring the same thing, and thus one could be deleted. However, the construct should at least still have three items, because SEM requires having at least 3 items per construct (Bollen 1989; Kelloway, 1998). Such three-indicator rule also assumes that the unique factor loadings (i.e., error terms) are uncorrelated. The CFAs were iterated until the items with the largest standard residuals were successfully removed and the statistics of overall model fit are satisfactory. The results shown in Table 5.5 indicate a good fit of the models according to the fit measures discussed above. The overall fit indices (Bentler and Bonett, 1980) range from 0.91 to 0.96. The loadings of each measurement item to their respective constructs are highly significant (P<0.001). For a clearer picture of the models, the diagrams and corresponding factor loadings of the two measurement models are provided in Figure 5.1 and Figure 5.2.




Note: Model fit statistics: Chi-square= 140.94; df=48; $\chi 2/df = 2.94$; RMSEA=0.090; SRMR=0.050; NFI=0.94; CFI=0.96; GFI=0.91.

Figure 5.1 Factor loadings in measurement model 1




Note: Model fit statistics: Chi-square= 125.73; df=48; $\chi2/df = 2.62$; RMSEA=0.082; SRMR=0.051; NFI=0.93; CFI=0.95; GFI=0.92.

Figure 5.2 Factor loadings in measurement model 2

Table 5.5 Confirmatory factor analysis results[a]

| **Construct /items** | **Factor loadings** | **t-value** | **Composite reliability[b]** | **AVE[c]** | **Cronbach's alpha** | **Model Fit** |
|---|---|---|---|---|---|---|
| **Measurement Model 1** (Dependent and the mediating variables) | | | | | | Chi-square=140.94; Df= 48 $\chi2/df$=2.94; RMSEA=0.090; SRMR=0.050; NFI=0.94; CFI=0.96; GFI=0.91 |
| Reusability of subsystems of platform-based products | | | 0.85 | 0.65 | 0.82 | |
| REU1 | 0.89 | 16.30* | | | | |
| REU3 | 0.74 | 12.75* | | | | |
| REU5 | 0.77 | 13.35* | | | | |
| Compatibility of subsystem interfaces of platform-based products | | | 0.85 | 0.65 | 0.81 | |
| COM1 | 0.77 | 13.53* | | | | |
| COM2 | 0.97 | 18.82* | | | | |
| COM3 | 0.65 | 10.89* | | | | |
| Platform cost efficiency | | | 0.90 | 0.75 | 0.87 | |
| COST1 | 0.90 | 17.27* | | | | |
| COST2 | 0.85 | 15.90* | | | | |
| COST3 | 0.84 | 15.42* | | | | |
| Platform cycle time efficiency | | | 0.89 | 0.73 | 0.83 | |
| TIME1 | 0.94 | 18.30* | | | | |
| TIME2 | 0.76 | 13.48* | | | | |
| TIME3 | 0.84 | 15.49* | | | | |

| Construct /items | Factor loadings | t-value | Composite reliability[b] | AVE[c] | Cronbach's alpha | Model Fit |
|---|---|---|---|---|---|---|
| **Measurement Model 2** (Independent variables) | | | | | | Chi-square=125.73; Df= 48 $\chi 2$/df=2.62; RMSEA=0.082 SRMR=0.051; NFI=0.93 CFI=0.95;GFI=0.92 |
| Formalized platform-based product development process | | | 0.87 | 0.70 | 0.84 | |
| FOR1 | 0.79 | 14.09* | | | | |
| FOR2 | 0.97 | 18.84* | | | | |
| FOR3 | 0.71 | 12.31* | | | | |
| Continuity of platform-based product development team | | | 0.88 | 0.70 | 0.84 | |
| CON1 | 0.93 | 17.73* | | | | |
| CON2 | 0.78 | 13.71* | | | | |
| CON4 | 0.80 | 14.39* | | | | |
| Design knowledge dissemination across a series of platform-based products | | | 0.75 | 0.50 | 0.72 | |
| DES1 | 0.75 | 11.44* | | | | |
| DES3 | 0.79 | 12.19* | | | | |
| DES5 | 0.56 | 8.41* | | | | |
| Existence of a champion in platform-based product development | | | 0.83 | 0.63 | 0.78 | |
| CHA2 | 0.87 | 15.59* | | | | |
| CHA4 | 0.93 | 17.14* | | | | |
| CHA5 | 0.54 | 8.74* | | | | |

[a] Single-item scales are not reported

[b] Internal composite reliability (ICR) is calculated according to Fornell and Larcker (1981) and should be greater than 0.7

$ICR = (\sum \lambda y_i)^2 / [(\sum \lambda y_i)^2 + \sum Var(\varepsilon_i)]$, where $\lambda$ is the loading of each item.

[c] Average variance extracted (AVE) score is calculated according to Fornell and Larcker (1981) and should be greater than 0.5.

$AVE = \sum(\lambda y_i)^2 / [ \sum(\lambda y_i)^2 + \sum Var(\varepsilon i)]$, where $\lambda$ is the loading of each item

* $p<0.001$ (2-tailed)

Moreover, in Table 5.5, individual item reliability, composite reliability, and the average variance extracted were calculated (Fornell and Larcker, 1981). Cronbach's alpha ranged between 0.72 to 0.87. All scores were above the recommended threshold 0.7 (de Vaus, 2002), which indicated that the measures were internally reliable (Nunnally, 1978). The composite reliability of each scale and measurement model ranged between 0.75 to 090. This exceeded the 0.70 threshold for acceptable reliability as recommended by Fornell and Larcker (1981). The average variance extracted (AVE) results ranged between 0.50 to 0.75, which also exceeded the 0.50 threshold recommended by Fornell and Larcker (1981), indicating that the variance due to measurement error was smaller than the variance captured by the construct. This showed that the specified indicators sufficiently represented the constructs they were intended to quantify (Hair et al, 1998). In addition, values of 0.7 for composite reliability and 0.5 for average extracted variance were also used as indicators of the internal consistency of the scales (Bagozzi and Yi, 1988), thus the internal consistency was also achieved in our study.

Convergent validity is used to assess in each model whether the items load significantly on the corresponding latent construct (Langerak et al., 2004). T-values associated with all items in our study exceeded the 0.001 level of significance (see Table 5.5). Together with the AVE, composite reliability and Cronbach's alpha suggest that the measurement scales for each construct demonstrate high convergent validity (Bagozzi et al, 1991; Hair, et al, 1998).

Discriminant validity is demonstrated when a construct does not correlate very highly with another construct from which it should differ (Venkatraman, 1989). Discriminant validity was examined by calculating the confidence intervals around the estimates of the interfactor correlations (Anderson and Gerbing, 1988). When a confidence interval for the estimate of the interfactor correlation does not include 1.0, discriminant validity is demonstrated. Since no confidence intervals of our construct correlations contained a value of one ($p<0.01$), it was concluded that the constructs possess discriminant validity.

Discriminant validity could also be verified by examining the square roots of AVE scores of the constructs (Fornell and Larcker, 1981). Following table confirms the discriminant validity of current study in that all the square roots of AVE scores in bold were greater than the level of correlations involving the constructs (same column and same row, off-diagonal cells in Table 5.6 and Table 5.7), implying that each constructs shares larger variance with its own measures than with other measures.

Table 5.6 Correlations and square roots of AVE of measurement model 1 (Dependent and mediating variables)[a]

| | REU | COM | COST | TIME |
|---|---|---|---|---|
| REU | **.807** | | | |
| COM | .461 | **.809** | | |
| COST | .337 | .303 | **.864** | |
| TIME | .055 | .233 | -.015 | **.854** |

[a] The square roots of AVE score of each construct is on the diagonal in bold. The inter-correlations among the constructs are on the off-diagonal

Table 5.7 Correlations and square roots of AVE of measurement model 2 (Independent variables)[a]

| | FOR | CON | DES | CHA |
|---|---|---|---|---|
| FOR | **.834** | | | |
| CON | .121 | **.839** | | |
| DES | .266 | .315 | **.707** | |
| CHA | .288 | .387 | .283 | **.796** |

[a] The square roots of AVE score of each construct is on the diagonal in bold. The inter-correlations among the constructs are on the off-diagonal

To fully satisfy and further determine the discriminant validity of the measurement models, following Bagozzi et al. (1991), we assessed the discriminant validity across the scales by estimating two-factor models for each possible pair of scales twice and computed differences in chi-square values for each set of the constructs: once constraining the correlation between the latent variables to unity and once freeing the parameter. The difference in chi-square values between constrained and unconstrained models provides statistical evidence of discriminant validity (Segars, 1997). When the results of a chi-square difference test assess the chi-square of the unconstrained model is significantly lower, discriminant validity is found. The critical value ($\Delta\chi2/ \Delta df > 3.84$ at the 0.05 level) indicates that all pair-wise tests established discriminant validity. The results of chi-square change in all models shown in Table 5.8 and Table 5.9, constrained and unconstrained, were significant ($p<0.05$), confirming that the constructs demonstrated discriminant validity. Such evidence of discriminant validity also indicates that multicollinearity is not a problem, according to Gray and Meister (2004).

Table 5.8 Discriminant validity for measurement model 1—chi square difference

| | Unconstrained | | Constrained | | Δ | | |
|---|---|---|---|---|---|---|---|
| | $\chi^2$ | df | $\chi^2$ | df | $\Delta\chi^2$ | Δdf | $\Delta\chi^2$/ Δdf |
| REU-COM | 17.92 | 8 | 263.15 | 9 | 245.23 | 1 | 245.23 |
| REU-COST | 39.50 | 8 | 321.63 | 9 | 282.13 | 1 | 282.13 |
| REU-TIME | 12.21 | 8 | 383.95 | 9 | 371.74 | 1 | 371.74 |
| COM-COST | 38.98 | 8 | 320.42 | 9 | 281.44 | 1 | 281.44 |
| COM-TIME | 12.67 | 8 | 371.84 | 9 | 359.17 | 1 | 359.17 |
| TIME-COST | 26.66 | 8 | 390.65 | 9 | 363.99 | 1 | 363.99 |

Table 5.9 Discriminant validity for measurement model 2—chi square difference

| | Unconstrained | | Constrained | | Δ | | |
|---|---|---|---|---|---|---|---|
| | $\chi^2$ | df | $\chi^2$ | df | $\Delta\chi^2$ | Δdf | $\Delta\chi^2$/ Δdf |
| FOR-CON | 32.00 | 8 | 371.97 | 9 | 339.97 | 1 | 339.97 |
| FOR-DES | 14.41 | 8 | 156.02 | 9 | 141.61 | 1 | 141.61 |
| FOR-CHA | 7.64 | 8 | 257.84 | 9 | 250.2 | 1 | 250.2 |
| CON-DES | 27.03 | 8 | 182.62 | 9 | 155.59 | 1 | 155.59 |
| CON-CHA | 41.71 | 8 | 301.61 | 9 | 25.99 | 1 | 25.99 |
| DES-CHA | 5.39 | 8 | 148.43 | 9 | 143.04 | 1 | 143.04 |

Therefore, according to the results of various analyses conducted, it was concluded that the measures had adequate unidimensionarity, internal consistency, convergent validity and discriminate validity. Hence, our measurement models fitted the data well and the testing of underlying relationship subsequently was appropriate.

## 5.4 Structural models

With the acceptable measurement model, we proceeded to estimate the structural model using structural equation modeling by means of LISREL 8.7 (Joreskog and Sorbom, 1993). Several variables were controlled for in the study's analysis: sales, number of employees of division and R&D expenditure ratio.

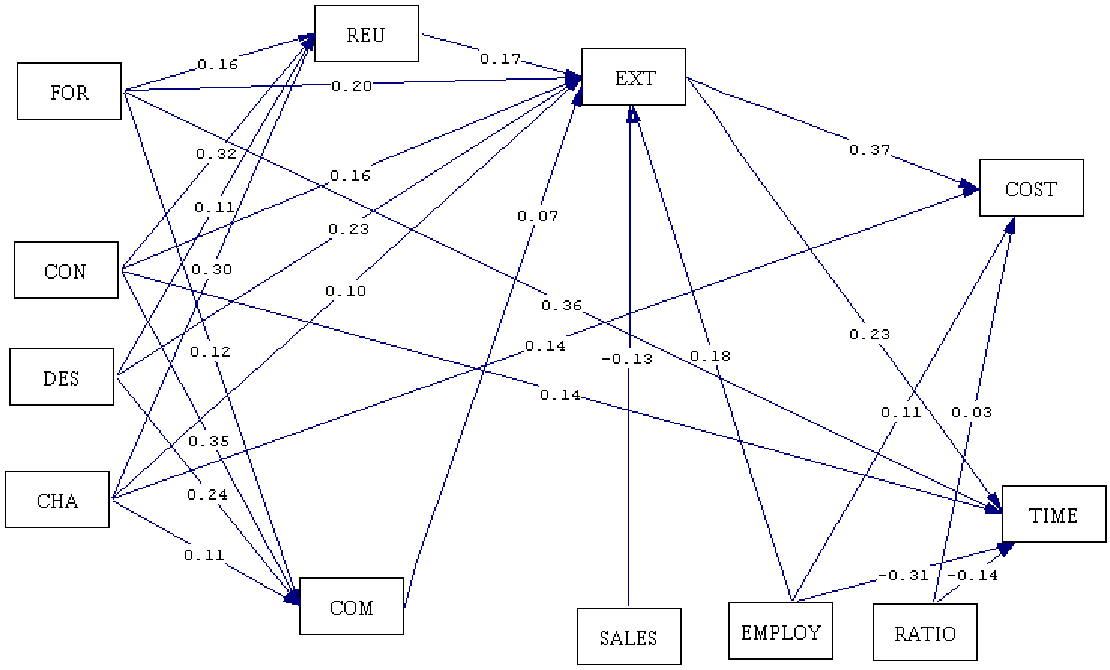
First, the descriptive statistics and intercorrelations are reported in Table 5.10. Results of the path analysis with the structural standardized coefficient are given in Figure 5.3 and corresponding t-values in Figure 5.4. The structural model fit indices for the overall model were Chi-square/df = 2.495; RMSEA=0.080; SRMR=0.036; NFI=0.97; CFI=0.98; and GFI=0.97, which were all well acceptable. Therefore, the indices indicated a very good model fit between the data and our research model.

Within LISREL, the test statistic is the T-value, which represents the parameter estimate, divided by the standard error (S.E.). It operates like the z-statistic in testing the parameter to determine estimate that it is statistically different from zero. For the .05 significance level, the t-values should exceed the critical value 1.96 and for the .01 significance level, the critical value is 2.576 (Hair et al. 1998). That is to say, based on a level of 0.05, the test statistic needs to be >±1.96 to reject the hypothesis, in which the estimate equals 0 (Byrne, 2001). Table 5.11 presents the standardized path coefficient estimates with corresponding t-values and significance levels for each path to test our hypotheses.

Table 5.10 Descriptive statistics and intercorrelations[a]

| | Items | Means | S.D. | EXT | REU | COM | COST | TIME | FOR | CON | DES | CHA | EMPLOY | RATIO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EXT** | 1 | 5.31 | 3.23 | | | | | | | | | | | |
| **REU** | 3 | 12.38 | 4.30 | .548** | | | | | | | | | | |
| **COM** | 3 | 13.48 | 4.14 | .485** | .461** | | | | | | | | | |
| **COST** | 3 | 15.47 | 4.27 | .488** | .337** | .303** | | | | | | | | |
| **TIME** | 3 | 15.05 | 5.09 | .257** | .055 | .233** | -.015 | | | | | | | |
| **FOR** | 3 | 13.66 | 4.18 | .472** | .312** | .253** | .278** | .273** | | | | | | |
| **CON** | 3 | 12.12 | 4.57 | .442** | .492** | .485** | .299** | .226** | .121 | | | | | |
| **DES** | 3 | 14.01 | 3.62 | .530** | .339** | .410** | .298** | .067 | .266** | .315** | | | | |
| **CHA** | 3 | 13.49 | 4.27 | .496** | .503** | .348** | .380** | .063 | .288** | .387** | .283** | | | |
| **EMPLOY** | 1 | 3.09 | .90 | .518** | .420** | .327** | .371** | .082 | .604** | .162* | .428** | .444** | | |
| **RATIO** | 1 | 2.02 | 1.04 | -.025 | -.052 | .039 | -.006 | -.089 | .099 | .068 | -.069 | -.123 | .007 | |
| **SALES** | 1 | 10.14 | 2.90 | -.361** | -.199** | -.227** | -.192** | -.134* | -.106 | -.271** | -.187** | -.262** | -.123 | .054 |

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
[a] EXT= Extensibility of platform-based products; REU= Reusability of subsystems of platform-based products; COM= Compatibility of subsystem interfaces of platform-based products; ; COST= Platform cost efficiency; TIME= Platform cycle time efficiency; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; DES= Design knowledge dissemination across a series of platform-based products; CHA= Existence of a champion in platform-based product development; EMPLOY= Number of full-time employees; RATIO= R&D expenditure as a percentage of sales; SALES=Last year sales.




Notes: Model fit statistics: Chi-square= 49.90; df=20; $\chi^2$/df = 2.495; RMSEA=0.080; SRMR=0.036; NFI=0.97; CFI=0.98; GFI=0.97

[a] REU= Reusability of subsystems of platform-based products; COM= Compatibility of subsystem interfaces of platform-based products; EXT= Extensibility of platform-based products; COST= Platform cost efficiency; TIME= Platform cycle time efficiency; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; DES= Design knowledge dissemination across a series of platform-based products; CHA= Existence of a champion in platform-based product development; EMPLOY= Number of full-time employees; RATIO= R&D expenditure as a percentage of sales; SALES=Last year sales.

Figure 5.3 Standardized path coefficients in the structural model [a]

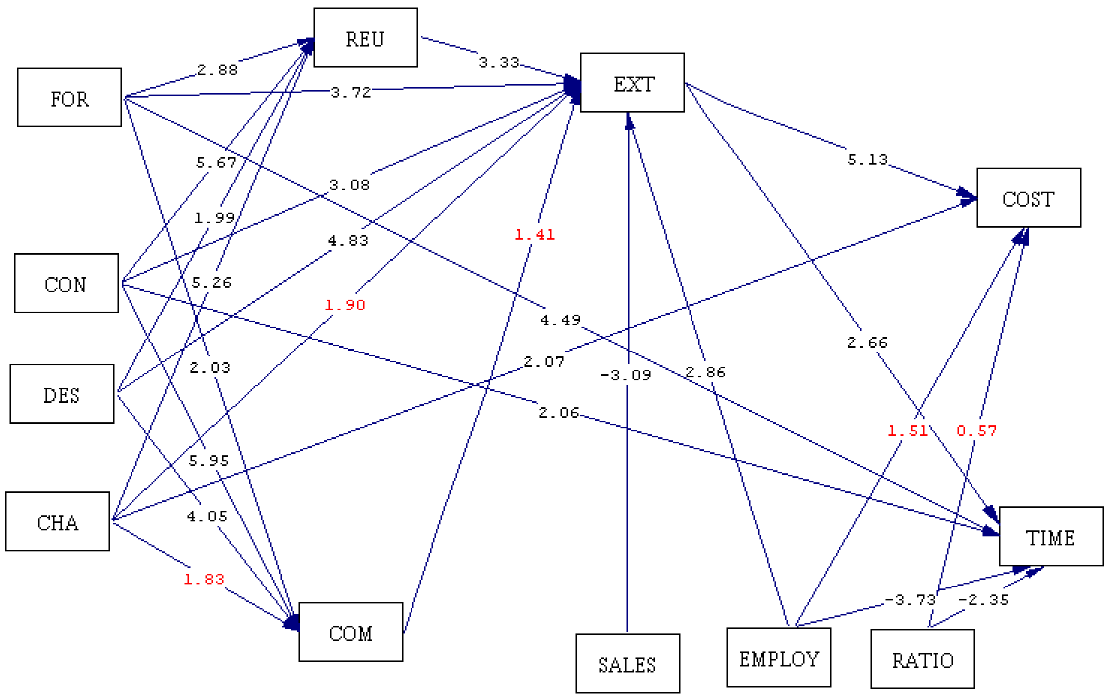



Figure 5.4 Corresponding t-values in the structural model

Table 5.11 Results from path model analyses [a]

| Hypothesis | Path from | Path to | Standardized Path Coefficient | T value | Conclusion |
|---|---|---|---|---|---|
| H1 | REU | EXT | 0.17 | 3.33** | Supported |
| H2 | COM | EXT | 0.07 | 1.41 | Not supported |
| H4a | FOR | REU | 0.16 | 2.88** | Supported |
| H5a | DES | REU | 0.11 | 1.99* | Supported |
| H6a | CON | REU | 0.32 | 5.67** | Supported |
| H7a | CHA | REU | 0.30 | 5.26** | Supported |
| H4b | FOR | COM | 0.12 | 2.03* | Supported |
| H5b | DES | COM | 0.24 | 4.05** | Supported |
| H6b | CON | COM | 0.35 | 5.95** | Supported |
| H7b | CHA | COM | 0.11 | 1.83 | Not supported |
| H4c | FOR | EXT | 0.20 | 3.72** | Supported |
| H5c | DES | EXT | 0.23 | 4.83** | Supported |
| H6c | CON | EXT | 0.16 | 3.08** | Supported |
| H7c | CHA | EXT | 0.10 | 1.90 | Not supported |
| H3b | EXT | TIME | 0.23 | 2.66** | Supported |
| H4d | FOR | TIME | 0.36 | 4.49** | Supported |
| H6d | CON | TIME | 0.14 | 2.06* | Supported |
| H3a | EXT | COST | 0.37 | 5.13** | Supported |
| H7d | CHA | COST | 0.14 | 2.07* | Supported |

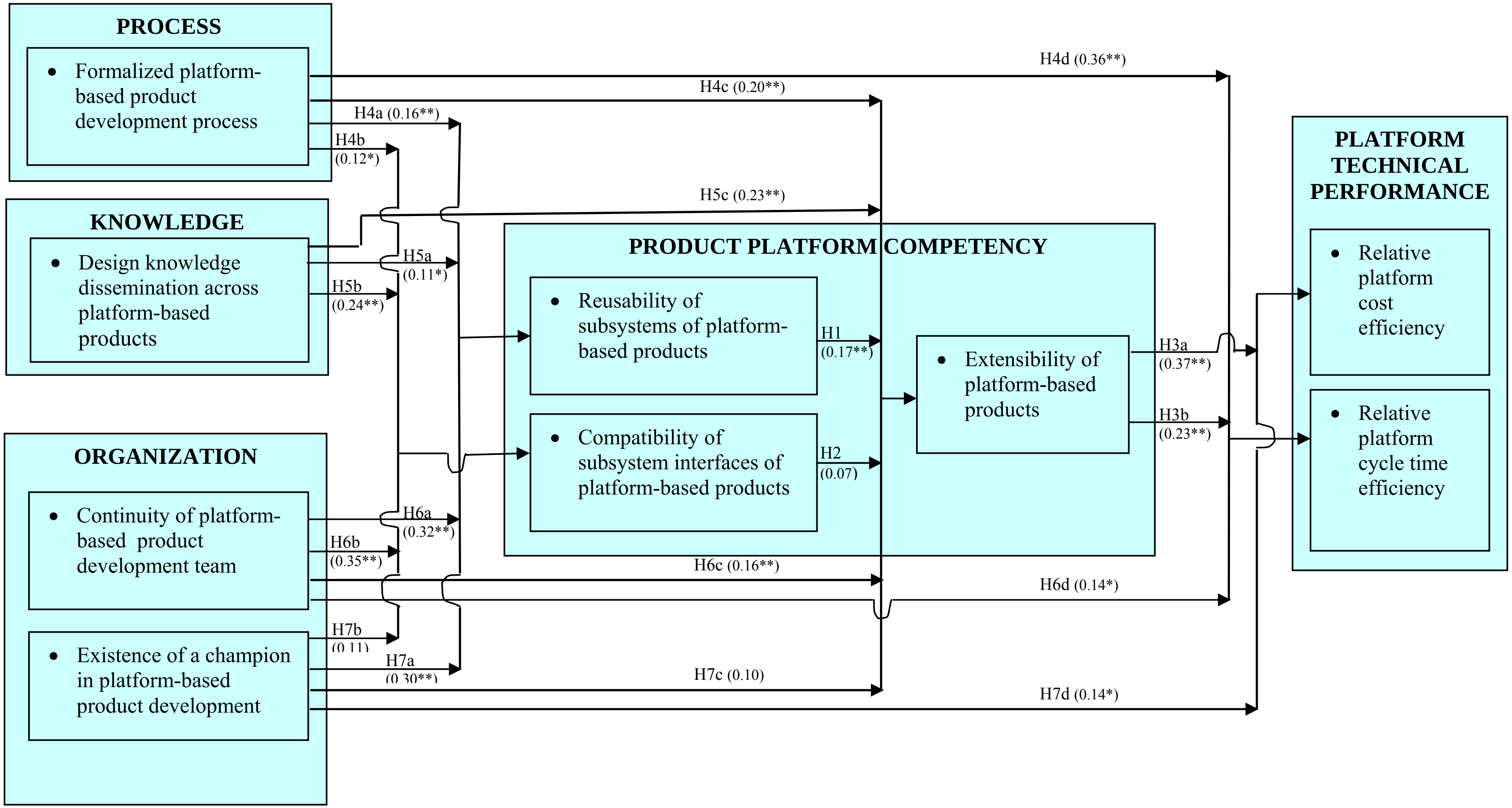
[a] Note: REU= Reusability of subsystems of platform-based products; COM= Compatibility of subsystem interfaces of platform-based products; EXT= Extensibility of platform-based products; COST= Platform cost efficiency; TIME= Platform cycle time efficiency; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; DES= Design knowledge dissemination across a series of platform-based products; CHA= Existence of a champion in platform-based product development

$\chi^2$= 49.90; df=20; $\chi^2$/df = 2.495; RMSEA=0.080; SRMR=0.036; NFI=0.97; CFI=0.98; GFI=0.97

* level of significance = 0.05

** level of significance = 0.01

As Table 5.11 indicates, all hypotheses are confirmed except H2, H7b and H7c, which are found to be not significant. Most of the other paths are significant at a level of $\alpha$ = 0.01 level, except H4b, H5a, H6d and H7d which are found to be significant at $\alpha$ = 0.05 level. Thus, the majority of main effects in our model have strong empirical support. Corresponding to the conceptual framework we presented in Figure 3.2, the results of the standardized path coefficients with corresponding hypotheses are summarized in Figure 5.5.




Note: Standardized path coefficients are in parentheses; Model fit statistics: Chi-square= 49.90; df=20; Chi-square /df = 2.495; RMSEA=0.080; SRMR=0.036; NFI=0.97; CFI=0.98; GFI=0.97.
** P<0.01, * P< 0.05

Figure 5.5 Standardized path coefficient

## 5.5 The moderating effects of technologically turbulent environment

Due to the restrictions of our sample size for a multi-sample analysis using Structural Equation Modeling (Kelloway, 1998; Maruyama, 1998), we applied a hierarchical multiple regression equation to test our hypothesized moderator effects (Frazier et al., 2004). Following the recommendation of Chin et al. (2003, pp.199), we standardized predictor and moderator variables, which is more suitable "for ordinal- and interval-level items, such as Likert-scaled attitudinal items". According to Aiken and West (1991), it can reduce the problems caused by multicollinearity and also make it easier to interpret the effects of the predictor and moderator. Therefore, to assess the threat of multicollinearity, we used the indicator of variance inflation factor (VIF) to diagnose multicollinearity first in each case below. We applied the rule of thumb of 5 as the threshold level for VIF as suggested by Chatterjee et al. (2000).

Following the procedures advised by Frazier et al. (2004) and Salomo et al. (2007), we first included the standardized predictor variables in model 1. Next, in model 2, we entered the standardized moderator variables; finally, we entered all the product terms into the regression equation in model 3. This approach is consistent with the arguments of West et al. (1996) and Aiken and West (1991), that all variables containing the interaction terms must be entered, and must be entered before the their product terms. Results of the moderating effects of technologically turbulent environment are presented in sections 5.5.1 to 5.5.5.

### 5.5.1 Moderating effects of technologically turbulent environment on reusability of subsystems of platform-based products

We examined the VIF value first as shown in Table 5.12. The range of VIF is from 1.160 to 1.663, which is well below the cut-off of 5. So, there is no sign of multicollineraity in this model.

The results of moderating analysis are reported in Table 5.13. We apply 0.1, 0.05 and 0.01 as the criterion to report different level significant levels, and use *, **, *** as the representative respectively, which are commonly applied in similar type of studies like

Bstieler (2005), Jones (2003) and Tatikonda (1999). The moderator hypothesis is supported if the interaction is significant, no matter what the main effects are (Bstieler, 2005; Baron and Kenny, 1986), as shown in Table 5.14.

Table 5.12 Test of multicollinearity[a]

| Variables | Collinearity Statistics | |
|---|---|---|
| | Tolerance | VIF |
| FOR | .662 | 1.510 |
| DES | .772 | 1.296 |
| CON | .784 | 1.276 |
| CHA | .717 | 1.395 |
| TEC | .601 | 1.663 |
| TECxFOR | .766 | 1.305 |
| TECxDES | .862 | 1.160 |
| TECxCON | .839 | 1.193 |
| TECxCHA | .764 | 1.309 |

[a] Dependent Variable: REU

Table 5.13 Results of hierarchical moderated regression—REU[a]

| | REU | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| **Main Effects** | | | |
| FOR | .156*** | .062 | .070 |
| DES | .110** | .077 | .074 |
| CON | .321*** | .303*** | .310*** |
| CHA | .303*** | .257*** | .253*** |
| **Moderator** | | | |
| TEC | | .222*** | .236*** |
| **Interaction Terms** | | | |
| TEC x FOR | | | -.006 |
| TEC x DES | | | -.076 |
| TEC x CON | | | -.049 |
| TEC x CHA | | | .116** |
| | | | |
| $R^2$ | .397 | .427 | .443 |
| Adjusted $R^2$ | .387 | .415 | .422 |
| $\Delta R^2$ | .397*** | .030*** | .016 |
| F | 38.990*** | 35.202*** | 20.516*** |

Note: REU= Reusability of subsystems of platform-based products; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; DES= Design knowledge dissemination across a series of platform-based products; CHA= Existence of a champion in platform-based product development; TEC= Technologically turbulent environment

[a] Standardized beta values are reported

* $p < .10$

** $p < .05$

*** $p < .01$

Table 5.14 Moderating effects of technologically turbulent environment on REU

| Hypothesis | Path from | Path to | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|
| H8a | FOR | REU | TEC | -.099 | Not supported |
| H9a | DES | REU | TEC | -1.448 | Not Supported |
| H10a | CON | REU | TEC | -.921 | Not Supported |
| H11a | CHA | REU | TEC | 2.062** | Supported |

** $p < .05$

"A significant interaction term XZ indicates that the effect of X on Y differs across the range of the moderator variable Z" (Dawson and Richter, 2006, pp.917). According to the recommendation of Cohen and Cohen (1983) and Frazier et al. (2004), we employed a standard plotting procedure to enhance the interpretability of our significant moderator effects and tested the statistical significance of the simple regression lines between the predictor and the dependent variable at low or high values of our moderator variable—technologically turbulent environment (TEC) (Dawson and Richter, 2006). For significant interactions of TEC x CHA on REU, the plots (Figure 5.6) show REU when the given CHA moves from low (one standard deviation below the mean) to high (one standard deviation above the mean) under a low and high technologically turbulent environment.

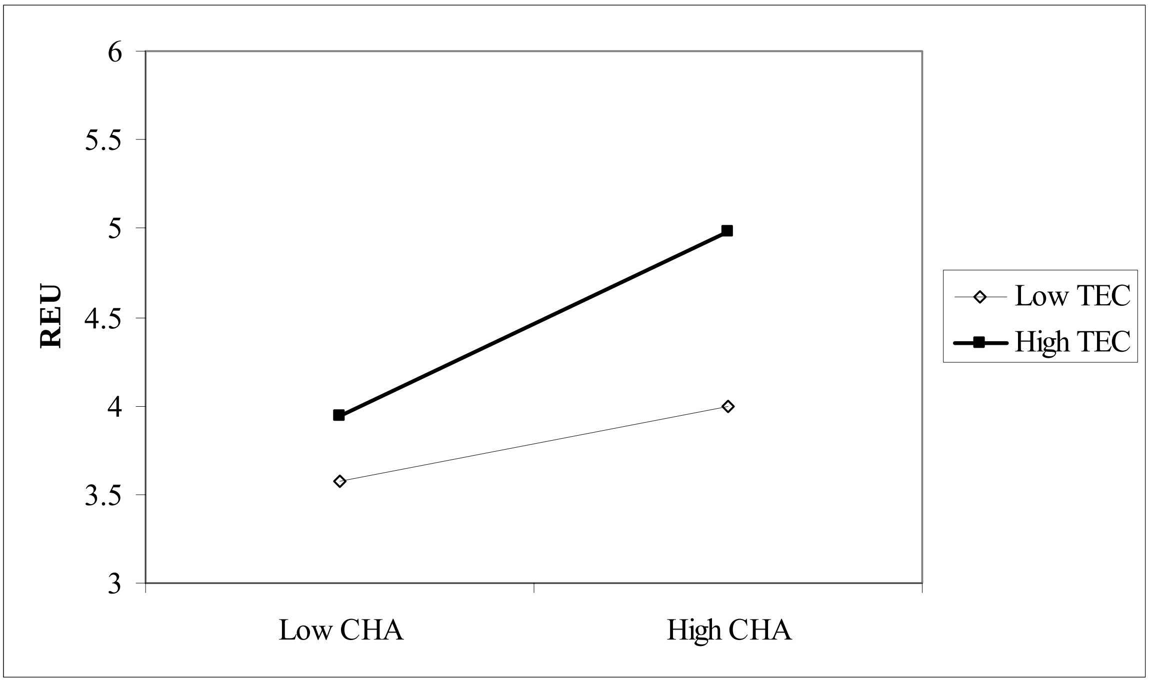



Figure 5.6 TEC x CHA interaction on REU

| | Unstandardized Coefficient | t-value | Sig. |
|---|---|---|---|
| Slope 1(in black): | 0.518 | 4.631 | .000 |
| Slope 2(in white): | 0.208 | 1.859 | .064 |

Note: REU= Reusability of subsystems of platform-based products; CHA= Existence of a champion in platform-based product development; TEC= Technologically turbulent environment

### 5.5.2 Moderating effects of technologically turbulent environment on compatibility of subsystem interfaces of platform-based products

We examined the VIF value first as shown in Table 5.15. The range of VIF is from 1.160 to 1.663, which is well below the cut-off of 5. So, there is no sign of multicollineraity in this model.

Table 5.15 Test of multicollinearity[a]

| Variables | Collinearity Statistics | |
|---|---|---|
| | Tolerance | VIF |
| FOR | .662 | 1.510 |
| DES | .772 | 1.296 |
| CON | .784 | 1.276 |
| CHA | .717 | 1.395 |
| TEC | .601 | 1.663 |
| TECxFOR | .766 | 1.305 |
| TECxDES | .862 | 1.160 |
| TECxCON | .839 | 1.193 |
| TECxCHA | .764 | 1.309 |

[a] Dependent Variable: COM

The results of moderating analysis and hypothesis testing are reported in Table 5.16 and Table 5.17 respectively.

Table 5.16 Results of hierarchical moderated regression—COM[a]

| | COM | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| **Main Effects** | | | |
| FOR | .115** | .060 | .056 |
| DES | .236*** | .217*** | .236*** |
| CON | .354*** | .343*** | .333*** |
| CHA | .111* | .084 | .107* |
| **Moderator** | | | |
| TEC | | .131* | .127* |
| **Interaction Terms** | | | |
| TEC x FOR | | | -.046 |
| TEC x DES | | | -.043 |
| TEC x CON | | | .136** |
| TEC x CHA | | | .056 |
| | | | |
| $R^2$ | .336 | .347 | .371 |
| Adjusted $R^2$ | .325 | .333 | .346 |
| $\Delta R^2$ | .336*** | .011* | .024* |
| F | 26.984*** | 25.035*** | 15.185*** |

Note: COM= Compatibility of subsystem interfaces of platform-based products; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; DES= Design knowledge dissemination across a series of platform-based products; CHA= Existence of a champion in platform-based product development; TEC= Technologically turbulent environment

[a] Standardized beta values are reported

* $p < .10$

** $p < .05$

*** $p < .01$

Table 5.17 Moderating effects of technologically turbulent environment on COM

| Hypothesis | Path from | Path to | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|
| H8b | FOR | COM | TEC | -.769 | NOT supported |
| H9b | DES | COM | TEC | -.763 | NOT supported |
| H10b | CON | COM | TEC | 2.399** | Supported |
| H11b | CHA | COM | TEC | .936 | Not supported |

** $p < .05$

Similarly, for significant interactions of TEC x CON on COM, we draw the plots in Figure 5.7 to show COM when the given CON moves from low (one standard deviation below the mean) to high (one standard deviation above the mean) under a low and high technologically turbulent environment.

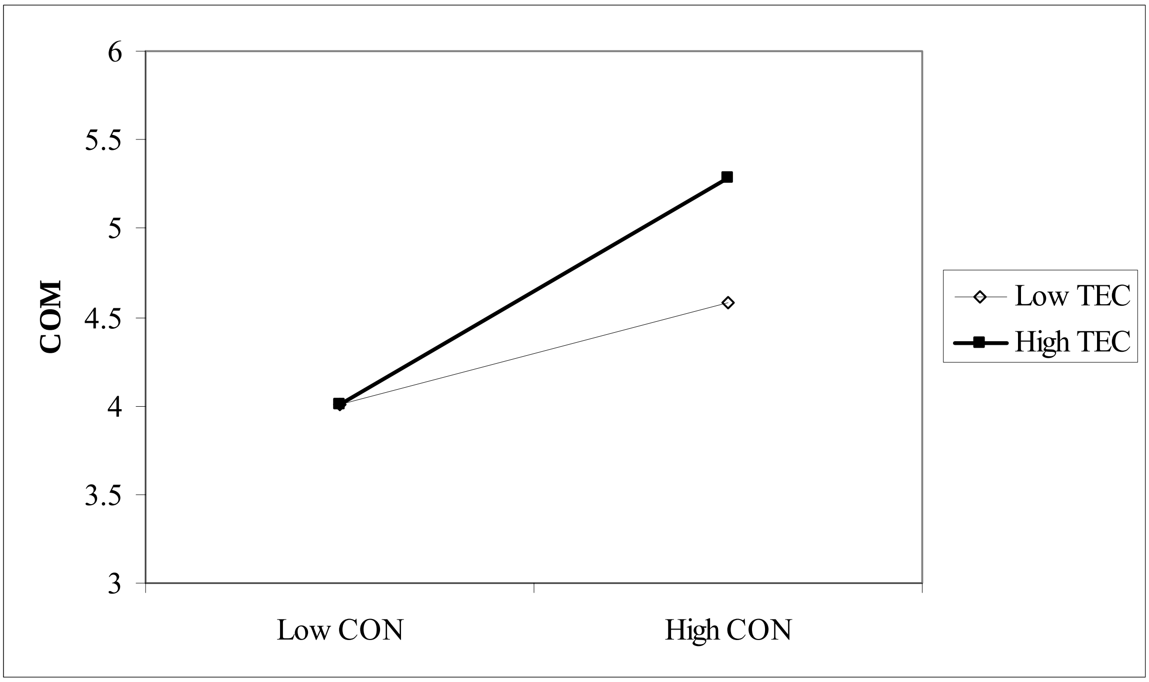



Figure 5.7 TEC x CON interaction on COM

| | Unstandardized Coefficient | t-value | Sig. |
|---|---|---|---|
| Slope 1(in black): | 0.635 | 6.385 | .000 |
| Slope 2(in white): | 0.285 | 2.418 | .016 |

Note: COM= Compatibility of subsystem interfaces of platform-based products; CON= Continuity of platform-based product development team; TEC= Technologically turbulent environment

### 5.5.3 Moderating effects of technologically turbulent environment on extensibility of platform-based products

We examined the VIF value first as shown in Table 5.18. The range of VIF is from 1.149 to 2.685, which is well below the cut-off of 5. So, there is no sign of multicollineraity in this model.

The results of moderating analysis and hypothesis testing are reported in Table 5.19 and Table 5.20 respectively.

Table 5.18 Test of multicollinearity[a]

| Variables | Collinearity Statistics | |
|---|---|---|
| | Tolerance | VIF |
| REU | .539 | 1.856 |
| COM | .611 | 1.637 |
| FOR | .587 | 1.703 |
| DES | .655 | 1.526 |
| CON | .606 | 1.651 |
| CHA | .610 | 1.639 |
| EMPLOY | .372 | 2.685 |
| SALES | .870 | 1.149 |
| TEC | .462 | 2.166 |
| TECxFOR | .721 | 1.387 |
| TECxDES | .848 | 1.179 |
| TECxCON | .810 | 1.235 |
| TECxCHA | .741 | 1.349 |

[a] Dependent Variable: EXT

Table 5.19 Results of hierarchical moderated regression—EXT[a]

| | EXT | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| **Control variables and Main Effects** | | | |
| REU | .174*** | .165*** | .175*** |
| COM | .093* | .090* | .067 |
| FOR | .207*** | .197*** | .172*** |
| DES | .238*** | .239*** | .267*** |
| CON | .102* | .100* | .114** |
| CHA | .123** | .122** | .164*** |
| EMPLOY | .096 | .068 | .041 |
| SALES | -.167*** | -.163*** | -.169*** |
| **Moderator** | | | |
| TEC | | .059 | .069 |
| **Interaction Terms** | | | |
| TEC x FOR | | | -.058 |
| TEC x DES | | | .152*** |
| TEC x CON | | | .037 |
| TEC x CHA | | | .121** |
| | | | |
| $R^2$ | .581 | .582 | .626 |
| Adjusted $R^2$ | .566 | .566 | .605 |
| $\Delta R^2$ | .581*** | .002 | .043*** |
| F | 40.347*** | 35.955*** | 29.341*** |

Note: EXT= Extensibility of platform-based products; FOR= Formalized platform-based product development process; DES= Design knowledge dissemination across a series of platform-based products; CON= Continuity of platform-based product development team; CHA= Existence of a champion in platform-based product development; REU= Reusability of subsystems of platform-based products; COM= Compatibility of subsystem interfaces of platform-based products; EMPLOY= Number of full-time employees; SALES=Last year sales TEC= Technologically turbulent environment

[a] Standardized beta values are reported

* $p < .10$

** $p < .05$

*** $p < .01$

Table 5.20 Moderating effects of technologically turbulent environment on EXT

| Hypothesis | Path from | Path to | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|
| H8c | FOR | EXT | TEC | -1.226 | Not Supported |
| H9c | DES | EXT | TEC | 3.459*** | Supported |
| H10c | CON | EXT | TEC | .822 | Not Supported |
| H11c | CHA | EXT | TEC | 2.577** | Supported |

**p < .05, ***p < .01

Similarly, for significant interactions of TEC x DES on EXT, we draw the plots in Figure 5.8 to show EXT when the given DES moves from low (one standard deviation below the mean) to high (one standard deviation above the mean) under a low and high technologically turbulent environment.

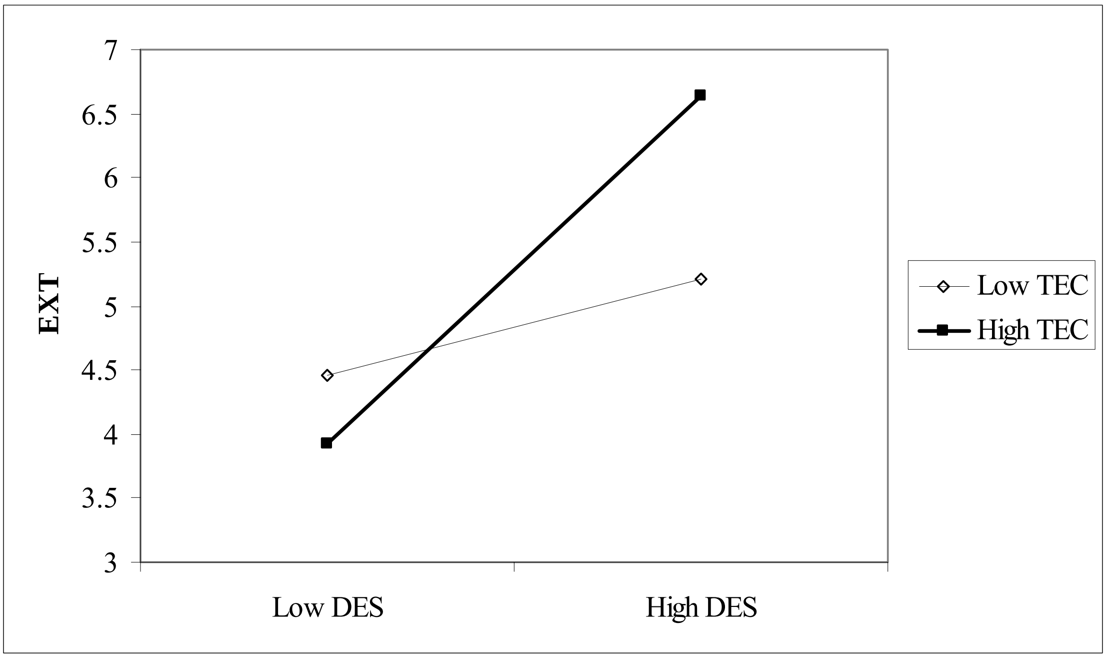



Figure 5.8 TEC x DES interaction on EXT

| | Unstandardized Coefficient | t-value | Sig. |
|---|---|---|---|
| Slope 1(in black): | 1.358 | 6.154 | .000 |
| Slope 2(in white): | 0.37 | 1.750 | .081 |

Note: EXT= Extensibility of platform-based products; DES= Design knowledge dissemination across a series of platform-based products; TEC= Technologically turbulent environment

In addition, for significant interactions of TEC x CHA on EXT, we draw the plots in Figure 5.9 to show EXT when the given CHA moves from low (one standard deviation below the mean) to high (one standard deviation above the mean) under a low and high technologically turbulent environment.

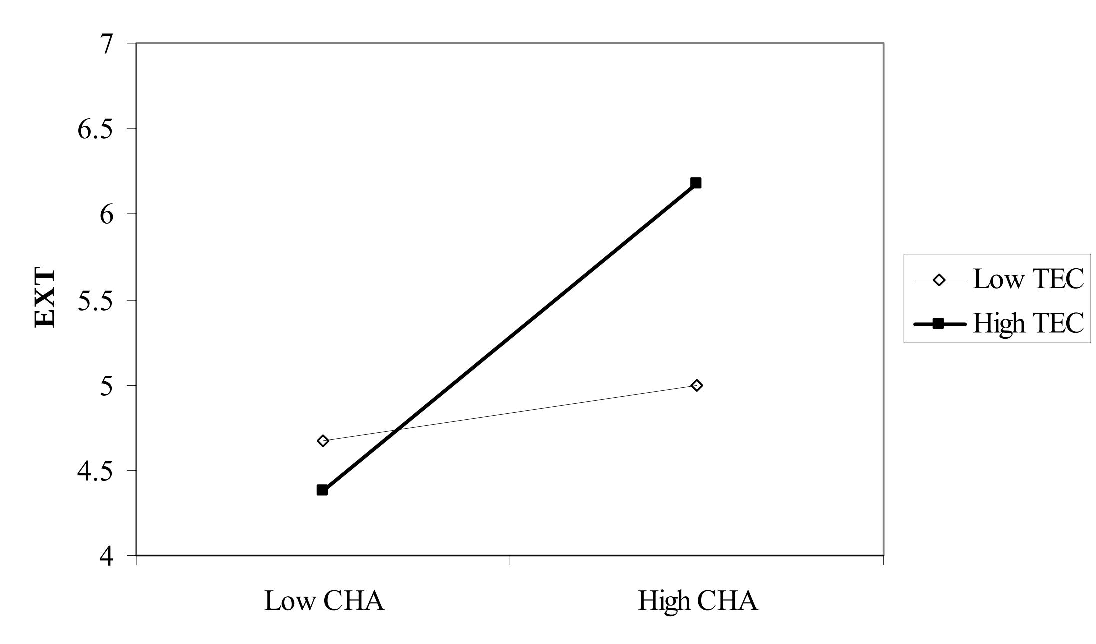



Figure 5.9 TEC x CHA interaction on EXT

| | Unstandardized Coefficient | t-value | Sig. |
|---|---|---|---|
| Slope 1(in black): | 0.896 | 3.842 | .000 |
| Slope 2(in white): | 0.166 | 0.806 | .420 |

Note: EXT= Extensibility of platform-based products; CHA= Existence of a champion in platform-based product development; TEC= Technologically turbulent environment

### 5.5.4 Moderating effects of technologically turbulent environment on platform cost efficiency

We examined the VIF value first as shown in Table 5.21. The range of VIF is from 1.023 to 2.065, which is well below the cut-off of 5. So, there is no sign of multicollineraity in this model.

Table 5.21 Test of multicollinearity[a]

| Variables | Collinearity Statistics | |
|---|---|---|
| | Tolerance | VIF |
| CHA | .663 | 1.508 |
| EXT | .594 | 1.685 |
| EMPLOY | .484 | 2.065 |
| RATIO | .978 | 1.023 |
| TEC | .493 | 2.030 |
| TECxCHA | .920 | 1.087 |

[a] Dependent Variable: COST

The results of moderating analysis are reported in Table 5.22.

Table 5.22 Results of hierarchical moderated regression—COST[a]

| | COST | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| **Control variables and Main Effects** | | | |
| CHA | .156** | .163** | .151** |
| EXT | .348*** | .371*** | .383*** |
| EMPLOY | .122* | .186** | .188** |
| RATIO | .021 | .020 | .018 |
| **Moderator** | | | |
| TEC | | -.117 | -.128 |
| **Interaction Terms** | | | |
| TEC x CHA | | | -.052 |
| | | | |
| $R^2$ | .274 | .281 | .284 |
| Adjusted $R^2$ | .262 | .266 | .265 |
| $\Delta R^2$ | .274*** | .007 | .003 |
| F | 22.385*** | 18.462*** | 15.513*** |

Note: COST= Platform cost efficiency; CHA= Existence of a champion in platform-based product development; EXT= Extensibility of platform-based products; EMPLOY= Number of full-time employees; RATIO= R&D expenditure as a percentage of sales; TEC= Technologically turbulent environment

[a] Standardized beta values are reported

* $p < .10$

** $p < .05$

*** $p < .01$

The hypothesis testing is shown in Table 5.23.

Table 5.23 Moderating effects of technologically turbulent environment on COST

| Hypothesis | Path from | Path to | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|
| H11d | CHA | COST | TEC | -.912 | Not supported |

### 5.5.5 Moderating effects of technologically turbulent environment on platform cycle time efficiency

We examined the VIF value first as shown in Table 5.24. The range of VIF is from 1.011 to 2.342, which is well below the cut-off of 5. So, there is no sign of multicollineraity in this model.

Table 5.24 Test of multicollinearity[a]

| Variables | Collinearity Statistics | |
|---|---|---|
| | Tolerance | VIF |
| FOR | .561 | 1.784 |
| CON | .769 | 1.301 |
| EXT | .535 | 1.868 |
| EMPLOY | .427 | 2.342 |
| RATIO | .960 | 1.042 |
| TEC | .481 | 2.079 |
| TECxFOR | .892 | 1.121 |
| TECxCON | .989 | 1.011 |

[a] Dependent Variable: TIME

The results of moderating analysis and hypothesis testing are reported in Table 5.25 and Table 5.26 respectively.

Table 5.25 Results of hierarchical moderated regression—TIME[a]

| | TIME | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| **Control variables and Main Effects** | | | |
| FOR | .332*** | .323*** | .314*** |
| CON | .171** | .165** | .163** |
| EXT | .132* | .125 | .138* |
| EMPLOY | -.213*** | -.240*** | -.259*** |
| RATIO | -.129** | -.127** | -.134** |
| **Moderator** | | | |
| TEC | | .053 | .048 |
| **Interaction Terms** | | | |
| TEC x FOR | | | -.085 |
| TEC x CON | | | .017 |
| | | | |
| $R^2$ | .157 | .159 | .165 |
| Adjusted $R^2$ | .139 | .137 | .137 |
| $\Delta R^2$ | .157*** | .001 | .007 |
| F | 8.803*** | 7.380*** | 5.764*** |

Note: TIME= Platform cycle time efficiency; FOR= Formalized platform-based product development process; CON= Continuity of platform-based product development team; EXT= Extensibility of platform-based products; EMPLOY= Number of full-time employees; RATIO= R&D expenditure as a percentage of sales; TEC= Technologically turbulent environment

[a] Standardized beta values are reported

* $p < .10$

** $p < .05$

*** $p < .01$

Table 5.26 Moderating effects of technologically turbulent environment on TIME

| Hypothesis | Path from | Path to | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|
| H8d | FOR | TIME | TEC | -1.341 | Not Supported |
| H10d | CON | TIME | TEC | 0.279 | Not Supported |

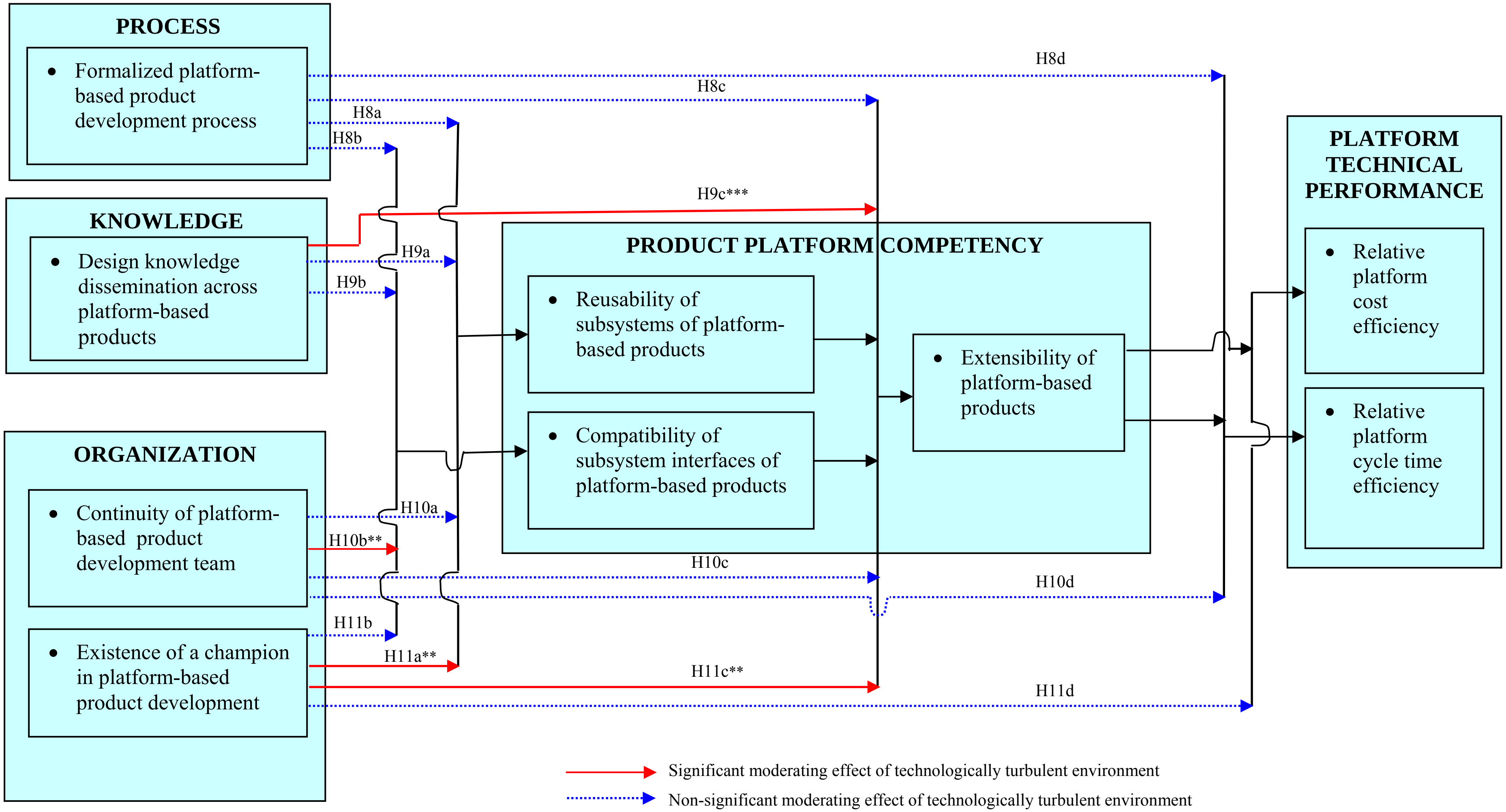
Collectively, all the results of moderating hypotheses could be summarized in Table 5.27 and shown in Figure 5.8.

Table 5.27 Results from moderating effects analysis

| Hypothesis | Path from | Path to | Corresponding Direct effect | Moderator | Interaction T-value | Conclusion |
|---|---|---|---|---|---|---|
| H8a | FOR | REU | H4a*** | TEC | -.099 | Not supported |
| H8b | FOR | COM | H4b** | TEC | -.769 | Not supported |
| H8c | FOR | EXT | H4c*** | TEC | -1.226 | Not Supported |
| H8d | FOR | TIME | H4d*** | TEC | -1.341 | Not Supported |
| H9a | DES | REU | H5a** | TEC | -1.448 | Not Supported |
| H9b | DES | COM | H5b*** | TEC | -.763 | Not supported |
| H9c | DES | EXT | H5c*** | TEC | 3.459*** | Supported |
| H10a | CON | REU | H6a*** | TEC | -.921 | Not Supported |
| H10b | CON | COM | H6b*** | TEC | 2.399** | Supported |
| H10c | CON | EXT | H6c*** | TEC | .822 | Not Supported |
| H10d | CON | TIME | H6d** | TEC | 0.279 | Not Supported |
| H11a | CHA | REU | H7a*** | TEC | 2.062** | Supported |
| H11b | CHA | COM | H7b | TEC | .936 | Not supported |
| H11c | CHA | EXT | H7c | TEC | 2.577** | Supported |
| H11d | CHA | COST | H7d** | TEC | -.912 | Not supported |

** $p < .05$

*** $p < .01$




*** P<0.01, ** P< 0.05

Figure 5.10 Moderating effects of technologically turbulent environment

## 5.6 Summary

We analyzed our survey results in this chapter. After justifying the validity of our data set in Section 5.2, we examined the measurement models of our multi-items scales through both exploratory factor analysis and confirmatory factor analysis in Section 5.3. With a high measurement quality achieved, we further tested the hypotheses regarding the direct effects in the structural model using LISREL 8.7 in Section 5.4. The results indicated very well model fit indices for our final structural model and most hypotheses were supported with convincing statistical results as summarized in Table 5.11 and Figure 5.5. Moderating effects were then tested using hierarchical multiple regression equation in Section 5.5. We found in the context of platform-based product development, technologically turbulent environment had some significant interaction effects with the four antecedents in our study on reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products respectively. The results of moderating hypotheses were summarized in Table 5.27 and Figure 5.10. We will discuss and identify the potential reasons in details in the next chapter.

# CHAPTER 6 Discussion

## 6.1 Introduction

In this chapter we summarize the research findings corresponding to the hypotheses we proposed in Chapter 3, and give our possible explanations accordingly. The chapter is organized in the following manner. Firstly, we discuss the impacts of product platform competency on platform technical performance. Next, we investigate the effects of management practices in platform-based product development. Finally, we examine the moderating effects of technologically turbulent environment.

## 6.2 Findings about product platform competency and its impact on platform technical performance

**Product platform competency**

In Chapter 3 we proposed product platform competency consists of reusability of subsystems, compatibility of subsystem interfaces, and extensibility of platform-based products. We further hypothesized that the former two elements, reusability of subsystems (H1) and compatibility of subsystem interfaces (H2) have positive effects on the third one, extensibility of platform-based products. As shown in Table 5.11, the path coefficient between subsystems reusability (REU) and product platform extensibility (EXT) has a positive significant ($p<0.01$) relationship, which confirms H1. However, in contrast to our expectation, the loading of the path between subsystem interfaces compatibility (COM) and product platform extensibility (EXT) is not significant (see Table 5.11). Therefore, H2 is not supported and what we hypothesized, subsystem interface compatibility has a positive effect on platform extensibility, does not appear to be the case. One possible reason could be that because we measure the compatibility of interface at the subsystem level, and since a product may not have that many subsystems, it is not difficult for design teams to overcome any incompatibility interface problems that may arise. Therefore the extensibility of platform product is not severely handicapped by this incompatibility issue. Another possible explanation could be that when compatibility is low, design engineers would be more likely to put efforts in understanding specification to gather relevant information and knowledge to make design changes in new products. In such situation, when the information can be accessed easily, engineers may not feel very much difficult to design new interfaces to incorporate new subsystems for new derivative products. Hence the effects of low compatibility on extensibility might be mitigated by a well-defined development process, frequent design knowledge dissemination and continuity of the development team. This was supported by the mediator effect tests, and the corresponding z-values are 3.50, 4.94 and 3.87 respectively and the significance levels are all at $p < 0.01$.

**Product platform competency's impact on platform technical performance**

As we discussed above, among the three elements of product platform competency, reusability of subsystems and compatibility of subsystem interfaces are regarded as the antecedents of extensibility of platform-based products in our study. Hence, extensibility of platform-based products has the main role in product platform competency and accordingly we hypothesized that it would have a direct effect on platform cost efficiency (H3a) and platform cycle time efficiency (H3b). Table 5.11 shows the loading of the path between product platform extensibility (EXT) and platform cost efficiency (COST) ($p<0.01$) is significant, which supports H3a. Similarly, we found product platform extensibility (EXT) was also positively associated with platform cycle time efficiency (TIME) ($p<0.01$) shown in Table 5.11, which is consistent with H3b. These results indicate that there exists a significant relationship between product platform extensibility and platform cost efficiency as well as platform cycle time efficiency.

## 6.3 Findings about the antecedents of product platform competency

In this study, we examined the roles of four management practices from Process, Knowledge, and People perspectives in platform-based product development (Robertson and Ulrich, 1998) and hypothesized them as the antecedents of product platform competency, which consists of reusability of subsystems, compatibility of subsystem interfaces, and extensibility of platform-based products.

In hypotheses H4a, H5a, H6a and H7a, we explored the effects of such four antecedents, i.e. formalized platform-based product development process (H4a); design knowledge dissemination across platform-based products (H5a); continuity of platform-based product development team (H6a) and existence of a champion in platform-based product development (H7a), on reusability of subsystems. The data provides empirical support for these four hypotheses that all are positive and significant as shown in Table 5.11. As a result, in order to increase the level of reusability of subsystems of platform-based products, one may increase the level of formalized development process, knowledge dissemination, continuity of development team and existence of product champion in the platform-based product development activities, all of which are consistent with our expectations.

Secondly, regarding the direct effect of such four antecedents, i.e. formalized platform-based product development process (H4b); design knowledge dissemination across platform-based products(H5b); continuity of platform-based product development team (H6b) and existence of a champion in platform-based product development (H7b), on compatibility of subsystem interfaces, it was found that all of these path coefficients are positive and significant ($p<0.01$) except for the path between "existence of a champion" and "compatibility of subsystem interfaces of platform-based products", which is not significant. Therefore, H4b, H5b and H6b are confirmed but H7b is not confirmed as stated in Table 5.11. The results emphasize the importance of formalizing the platform-based product development process, disseminating design knowledge across platform-based products and keeping the development team continuity from on product to another, as a way of enhancing the compatibility of subsystem interfaces of platform-based products. However, contrary to expectations, compatibility of subsystem interfaces did not rely on existence of a champion in platform-based product development. Firstly, one possible reason for this non-significant result could be that while product champions may indeed play an important role in most organizations; however, in reality, a champion is usually a senior manager in the organization who tends to focus on strategic issues such as product strategy and/or other particular obstacles involving technical issues rather than on detailed aspects of product development. Compared to making the decision on reusing the subsystems, the design of compatibal interfaces are more detailed activities related. Therefore, whether or not to apply previous subsystems in a new derivative product may rely more on a product champion's judgment than on the interface compatibility of the subsystems involved. Secondly, champion's limited impact on the compatibility of subsystem interfaces could be largely explained by the existence of a formalized platform-based product process as observed by Kahn et al. (2006) and Markham and Griffin (1998). This could be because in well organized companies, where members closely adhere to the product development process and are aware of the review criteria, their role is less crucial (Kahn et al., 2006). It seems likely that organizations engaged in platform product development will have a well structured product development process given the large investment involved in platform product development. Having a systematic process, developed from their previous product development experiences, will ensure that the right tasks are undertaken and that the correct information is accessed in a timely manner from the appropriate sources (Kleinschmidt et al., 2007; Cooper, 1999). Consequently, in platform-based product development, the compatibility of subsystem interfaces depends more on the formalized process than on the existence of a champion. Thus, the existence of a champion may have little impact on interface compatibility. Thirdly, maybe it is also because compared to the interface compatibility, reusability is more like a strategic issue that has an immediate impact on cost (i.e. how many subsystems can be reused or will be reused in derivative products affect the design cost and production cost). Whereas interface compatibility design is seen as a more technical/operational issues that the designers have to deal with rather than the champions.

Thirdly, taken together, the four management practices were also hypothesized to have a positive impact on extensibility of platform-based products in H4c, H5c, H6c and H7c respectively. The results shown in Table 5.11 indicate that H4c ($p<0.01$), H5c ($p<0.01$) and H6c ($p<0.01$) were strongly supported. This means the extensibility of platform-based products is likely to be improved by a formalized platform-based product development process; design knowledge dissemination across platform-based products and continuity of platform-based product development team, which may also be seen as its antecedents. However, no significant links were found between existence of a champion in platform-based product development and extensibility of platform-based products (H7c). Contradicting our expectation, increase in the degree of champion involvement in platform-based product development does not have a strong effect on enhancing the degree of product platform extensibility. The similar reasoning of H7b can be applied to this result too. The contribution of a product champion may be confounded with other factors, such as formalized new product development process (Markham and Griffin, 1998). However, after further looking at the coefficient of the path shown in Table 5.11, we found the t-value is 1.90, just slightly below the critical value 1.96 for the .05 significance level. Although in general there is no significant relationship existing here, it could be interesting to further examine the difference in the relationship between existence of a champion and product platform extensibility under different technologically turbulent environments, as discussed in Section 6.4.

On the other hand, the extensibility of platform-based products is supposed to be an important determinant of platform cost efficiency that is confirmed in H3a. We also hypothesized existence of a champion is another important factor that may positively impact the platform cost efficiency (H7d). Our data confirms this hypothesis shown in Table 5.11, as the existence of a champion in platform-based product development has a positive significant ($p<0.05$) relationship with platform cost efficiency. This finding suggests that the existence of product champion in platform-based product development has a great influence on saving cost in successive products. This may be because product champions may indeed play an important role in most organizations. They do involving in problem solving and their participations are at deciding the direction/strategy of solving a problem and those problems which could involve multiple functions/teams/depts. Therefore, in reality, a champion not only tends to focus on strategic issues such as product strategy, but also addresses particular technical difficulties and solves those critical problems. However, the cost pertained to different solutions to such particular technical difficulties and critical problems may vary very differently. According to Martin and Ishii (1996), four critical aspects were revealed among the cost factors in their case study, from which they may significantly reduce the cost in DFV (design for variety). This seems to suggest the presence of Pareto's principle-- that most of the problems may stem from the few vital factors. Therefore, when the product champions can efficiently apply his related knowledge and experience by identifying and solving these particular technical difficulties and critical problems, they have strong impact on the cost efficiency of platform-based product development.

In addition, we also argued that not only the extensibility of platform-based products (H3b), but also a formalized platform-based product development process (H4d), and continuity in the platform-based product development team (H6d), would have clear positive effects on platform cycle time efficiency. The results shown in Table 5.11 provide empirical support for both H4d and H6d, as both a formalized platform-based product development process and continuity in the platform-based product development team show significant positive relationships with platform cycle time efficiency ($t = 4.49$, $p<0.01$ and $t = 2.06$, $p<0.05$). In other words, a formalized development process and stability in the development team appear to enhance platform performance in terms of cycle time efficiency. This may enable firms to spend less time than their competitors in developing successive products based on an existing platform, leading to time savings.

Our results are consistent with previous studies in the single product development. Although Katz (1982) asserts team instability may be helpful in challenging and improving existing methods and accumulated knowledge because new team members may have advantages in bringing fresh ideas and approaches, Kessler and Chakrabarti (1999) found team instability had a significant negative influence on development cycle time based on their study of 75 new product development projects. Such finding is further supported by Akgun and Lynn (2002)'s empirical study, in which a significant positive relationship between team stability and speed-to-market has been found. In the setting of platform-based product development, our findings provide empirical support for the continuity of platform-based development team. This result could be explained by Fredrickson and Iaquinto (1989), who argued that high levels of continuity could make decision processes more efficient. Due to the large similarity of the functions among the derivative products from one common platform, the design activities could be more efficient than designing the same amount of singular products that have no common base. Taking this advantage, the continuity of platform-based product development team is not surprising to have significant impact in increasing development time efficiency, whereas it does not take the design quality as the price.

In addition, using a formal process has been demonstrated to increase success for product development (Cooper and Kleinschmidt, 1985). Griffin (1997) explicitly argues that a formal process may reduce cycle time and demonstrates that it may reduce cycle time even more for more complex products. Given that the goal of platform development is to develop a series of products, therefore we view developing derivative products as a whole rather than individually. Although the individual product development from the platform could be no more complex than traditional single product development, however, platform-based product development should reflect the stream of products based and quite often one product is in development while another new derivative product may also have started. Therefore, platform-based product development involves more resources, more people and more products with more functions at the same time than single product development, and it could be regarded as one particular kind of such complex development work. Hence, our findings provide empirical evidence to support Griffin's (1997) point of view and confirms the importance of formalized process in the context of platform-based product development. This is because such approach not only can govern the development activities with a sense of structure and sequence, but also can be efficiently re-applied for follow-on products derived from the same platform. This approach is especially useful in organizing the management of interaction and interfaces and avoiding the ambiguity what to work on and when (Griffin, 1997; Tatikonda and Montoya-Weiss, 2001; Salomo et al. 2007),

## 6.4 Findings about the moderating effects of technologically turbulent environment

To assess the interaction effect of the four exogenous management practices and the technologically turbulent environment, we performed moderating analysis as illustrated in Section 5.5 and the overall results are shown in Table 5.27 and Figure 5.8.

We examined the moderating effects of technologically turbulent environment on the four management practices and reusability of subsystems, compatibility of subsystems interfaces, extensibility of platform-based products, platform cost efficiency and platform time efficiency. In all of the interaction analyses, four significant interactions were found as shown in Table 5.27 and Figure 5.8. These included interactions between existence of a champion in platform-based products and technologically turbulent environment for reusability of subsystems (H11a, $t=2.062$, $p<0.05$), interactions between continuity of platform-based product development team and technologically turbulent environment for compatibility of subsystem interfaces (H10b, $t=2.399$, $p<0.05$), interactions between design knowledge dissemination across a series of platform-based products and technologically turbulent environment for extensibility of platform-based products (H9c, t=3.459, $p<0.01$) and interactions between existence of a champion in platform-based products and technologically turbulent environment for extensibility of platform-based products (H11c, t=2.577, $p<0.05$) . Thus hypotheses H9c, H10b, H11a and H11c are supported, while other moderating hypotheses are not supported.

We may assert that the strength of the relationship between existence of a champion in platform-based product development and reusability of subsystems of platform-based products is greater in an environment characterized by high technological turbulence than in an environment characterized by low technological turbulence (H11a). One possible explanation for such moderating effect may be in a high technologically turbulent environment, along with the technology changes, the subsystems tend to change more quickly than in a low technologically turbulent environment, which makes it harder for the development team to decide which subsystem to create and which subsystem to reuse. Therefore, in such situation, existence of a champion in platform-based product development may take on a more important role to help development team to make the decision, in which they try to use as many existing subsystems as possible based on their previous rich knowledge and experience. Hence, it may increase the chance to reuse existing subsystems.

Similarly, regarding the moderating effect of H11c, existence of a champion also shows a different importance to the extensibility of platform-based product. We noticed that the relationship between existence of a champion and product platform extensibility is not significant as H7c shows in Table 5.11. However, such conclusion may be different under different technologically turbulent environments as shown in Figure 5.7. There is a clear difference of the slope of existence of a champion to extensibility of platform-based product development. In a high technologically turbulent environment, the coefficient is significant at $P<0.001$ level, but in a low technologically turbulent environment, the coefficient is not significant at all. Such comparisons have been summarized in Table 6.1.

Table 6.1 Comparisons of effects of CHA on EXT

| Hypothesis | | Independent | Dependent | t-value | Sig. | Conclusion |
|---|---|---|---|---|---|---|
| H7c | | CHA | EXT | 1.90 | .059 | Not supported |
| H11c | High TEC | CHA | EXT | 3.84 | .000 | Supported |
| | Low TEC | CHA | EXT | 0.81 | .420 | |

Note: EXT= Extensibility of platform-based products; CHA= Existence of a champion in platform-based product development; TEC= Technologically turbulent environment

This may be because in high technological turbulence, the development team may face more uncertainties when developing derivative products. Then presence of a champion, especially a strong one, will likely rally and drive team members to overcome these difficulties. Hence the importance of existence of champions to product platform extensibility appears more noticeably in a high technologically turbulent environment than in a low technologically turbulent environment.

Moreover, H10b which is confirmed in our study shown in Table 5.27 posits that technologically turbulent environment moderates the relationship between continuity of platform-based product development team and compatibility of subsystem interfaces. This finding suggests that in a high technologically turbulent environment, team stability in developing a range of derivative products has more impact on maintaining previous knowledge in subsystem design, which results in increasing the compatibility of subsystem interfaces. This is contrary to the argument of Akgun and Lynn (2002), who suggest that organizations do not need overly stable teams, particularly under highly turbulent environments. They further state that shaking up the team may improve team learning and accelerate speed (Akgun and Lynn, 2002). However, such suggestion is made in the context of individual projects. When studying the whole derivative products based on one common platform as one unit, the understanding of team stability should be extended to a range of related products and take their common characteristics into consideration. As in a product family series, follow-up products share a lot of similarities with previous products. When changing existing products to create new products, the knowledge about previous development will be particularly helpful. Therefore, personnel turnover which is recommended in high technological turbulence in singular product development (Akgun and Lynn, 2002), may not be appropriate in the context of platform-based product development. On the contrary, the positive effect of continuity of platform-based development team on compatibility of subsystem interfaces is significantly strengthened in a high technologically turbulent environment.

In addition, according to our moderating results shown in Table 5.27 and Figure 5.8, we also find that the strength of relationship between design knowledge dissemination across a series of platform-based products and extensibility of platform-based products is greater in an environment characterized by high technological turbulence than in an environment characterized by low technological turbulence (H9c). This may be interpreted as in a low technologically turbulent environment the new technique and new design knowledge do not evolve as fast as in a high technologically turbulent environment. Consequently, the impact of knowledge dissemination across platform-based products on product platform extensibility is stronger under high technological turbulence than under low turbulence.  This is consistent with the conclusion of Petersen et al. (2003), who claimed that when technological turbulence was present, companies need a high level of information sharing. This may lead to a prompt awareness of external or internal changes (Bij et al. 2003).  Therefore, in high technologically turbulent environments, design knowledge dissemination across platform-based products may play a more important role to contribute in expanding the capacity of the platform to produce derivative products from it.

Furthermore, we do not find significant moderating effects (H8d, H10d and H11d) between management practices and technologically turbulent environment both on platform cost efficiency and platform cycle time efficiency as shown in Table 5.23 and Table 5.26. These findings might support the conclusions of Petersen et al. (2003). Technology turbulence does not necessarily affect final product cost and time performance. One possible interpretation is that the performance outcome associated with technology turbulence can be mitigated by other determinant factors in our study, such as the product platform extensibility and/or the exogenous management practices (e.g. existence of a champion, formalized platform-based product development process).

On the other hand, we also noticed that the other hypothesized moderating effects (H8a, H8b, H8c, H9a, H9b, H10a, H10c and H11b) are not significant. This is possibly due to the technological characteristics of the platform-based products. Based on the results of the empirical study of Tatikonda (1999), derivative product development undertakes lower levels of new technology than initial platform development. This is consistent with the statement of Koufteros et al. (2005), who indicate that the technical uncertainties are lower in derivative product development, which is seen as an incremental technology innovation approach. Applying Henderson-Clark's (Henderson and Clark, 1990) incremental and radical innovation theory in platform-based product development, the initial product platform could be viewed as the dominant design (i.e. architecture). Once such dominant design is established, the follow-up product development based on it, takes the form of improvements in the components within the framework of the stable architecture. Therefore, platform-based product development within one platform is largely of incremental and modular innovation. At that time, the elaboration and refinement of existing knowledge become the focus (Henderson and Clark, 1990). According to the technology typological theory of projects (Raz et al., 2002), platform-based product development can be categorized into Type B - medium-tech projects, which use mainly existing technology and changes are normally limited including improvements and modifications and may cause the interaction effects to be insignificant. Therefore, we may argue that the impact of technologically turbulent environment on platform-based product development activities is relatively low as most of the derivative products are based on existing knowledge and from the basis of the initial dominant product forms. Such relative stability allows the engineers of new products to build incremental changes upon previous products and take much lower levels of risks and commitment (Jones, 2003). Therefore, no matter whether the external technological turbulence is high or low, companies may still keep their management practices stable. These could be the main reasons why the moderating effects of technologically turbulent environment on our four management practices are not as much significant as we estimated.

Another possible explanation is that according to the platform strategy (Koufteros et al., 2005; Ulrich and Eppinger, 2002), companies often plan multiple generations in advance before they design the initial core product. After that, they are reluctant to make radical changes for their future extensions due to resource limitation and the desire to develop derivative products at lower costs and faster time to markets (Koufteros et al., 2005). Thus, it requests a higher level of forecasting capabilities for the companies to take the technological turbulence into consideration before they make the platform strategy decision. But once the decision is made, the technologically turbulent environment will have little impact on their platform-based product development as our empirical results showed.

Moreover, we find that there are certain companies in our study that despite facing a rapidly changing technology environment are adopting the platform approach. This seems to contradict the product life cycle theory. According to the product life cycle theory, life cycle of a product comprises four stages (Levitt 1965; Cox 1967; Polli and Cook 1969). During the early phase—i.e. the "introduction" and "growth" stages, the market, the product/technology, the manufacturing process and the structure of the industry evolve rapidly, and that the industry is in a state of ferment. In contrast, the late phase—i.e. the "maturity" and "decline" stages, is often characterized by relatively stable industry conditions (Porter, 1980; Staudt et al., 1976; Thorelli and Burnett, 1981). According to Badwin and Clark (1997), the interfaces (the scheme by which the modules interact and communicate) and the standards (the design rules to which the modules conform) are the two prerequisites for modular product architectures. Since modular product architecture is the basis of platform-based product development (Halman, et al. 2003), firms at the introduction stage rarely can take the platform strategies to develop their new products because both the interfaces and standards are not stable due to the fast changing market and technology involved. Therefore it is often assumed that firms can only adopt the platform approach at the "growth" stage or later stages in product life cycle. One possible explanation is that building competency in the product platforms requires a long period of time. Consequently, companies have to start early in order to gain the benefits from the application of product platform, although the external environments are unstable at that time. In this situation, companies need to overcome the difficulties caused by the turbulent environment, and meet the even high requirements in their product platform design to accommodate the many potential changes. But compared to the huge benefits that the platform-based product development may bring to them, many companies still choose platform.

## 6.5 Summary

In this chapter we summarized our research findings based on our empirical data and gave the possible explanations accordingly. Our empirical results confirmed that platform-based management practices did impact the product platform competency, and they together impacted the final platform technical performance in terms of cost efficiency and cycle time efficiency. In addition, four moderating effects of technologically turbulent environment with platform-based product management practices were found, while the others were not supported.

# CHAPTER 7 Conclusions and Future Study

## 7.1 Introduction

In Chapter 2, we proposed the research question and its three sub-questions. These questions are satisfactorily answered by the results of our study through the procedure of hypotheses development and validation by the empirical survey research. In regard to our first sub-research question, our results lend support to the concept of product platform competency which comprises reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products. In regard to our second sub-research question , our results show that formalized development process, design knowledge dissemination across platform-based products, continuity of platform-based product development team and existence of a champion in platform-based product development significantly affect product platform competency, which can be regarded as the antecedents of product platform competency. In regard to our third sub-research question, our findings further suggest that in a high technologically turbulent environment, some of these factors have even greater impact on product platform competency. As such, the results of this study provide contributions and implications for academics as well as practitioners (i.e. managers). Such contributions and implications are addressed first in the following sections. Nevertheless, the findings are subjected to several limitations and therefore we discuss the limitations of this study subsequently and point out the potential future research directions in this area.

## 7.2 Contributions and implications of the study

### 7.2.1 Contributions and implications to researchers

This study makes four principal contributions to the existing literature. The first contribution of this study to the academic field is derived from the new constructs developed in our study, which may be applied in future research. We drew the key elements of platform from Robertson and Ulrich (1998) and proposed the concept of product platform competency in our study (see Figure 3.2). To the best of our knowledge, it is the first time that such concept is proposed. Although prior work have advanced our understanding of the importance of product variety (e.g. Kim et al., 2005) and derivative product introduction rate (e.g. Jones, 2003), they do not give a clear definition of product platform competency and lack formal empirical testing of its role in platform-based product development. Following the "component" perspective defined by Robertson and Ulrich (1998), we identify product platform competency to be composed of three elements, including reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products. Based on our findings, strong evidence of an association has been provided between the product platform extensibility as the main element in product platform competency and the platform performance. This adds to a better understanding of what leads to success in platform-based product development and contributes to future research by providing a more relevant and critical specified set of constructs on this topic.

Our second contribution is the development of constructs specifically for platform development based on previous studies and our field interviews. In our study, we adapted the 'platform performance metrics' proposed by Meyer et al. (1997) and included all derivative products in our unit of analysis. Previous studies measured success either on the single project (product) level or at the program (firm) level (Johne and Snelson, 1988); little research has measured performance at the product platform level. Some studies directly borrowed items from previous research and ignored the unique context of platform-based product development when measuring the performance of a product family (e.g. Kim et al., 2005; Tatikonda, 1999). Additionally, whereas previous researchers only considered relative performance within a single organization, we included performance relative to external competitors, which might be a more comprehensive approach.  These performance measures, validated in our study, should help researchers to conduct more surveys in platform development which so far has largely been done in the form of case studies.

Thirdly, our study provides an in-depth quantitative analysis of good management practices in platform-based product development and confirms the links among these management practices, product platform competency, and product platform performance in terms of cost efficiency and cycle time efficiency. While some prior studies provided some theoretical conclusions in the platform development area (e.g. Meyer and Lehnerd, 1997; Meyer and Utterback, 1993; Jones, 2003; Tatikonda, 1999), we contributed a new framework with novel insights and provided a systematic empirical investigation to support it, which expands existing literature on this topic. In particular, the four key elements in platform-based product development adopted from Robertson and Ulrich (1998) (i.e. process, knowledge, organization and components) are supported by the findings of our statistical analysis. But these elements may play different roles in platform-based product development, in which the former three elements could be regarded as the antecedents of the fourth one—components, which is also viewed as product platform competency in our study. As such, our study provides a more explicit and detailed view of how these factors are interrelated and influence platform-based product development performance.

Another main theoretical implication of this study is that we examined the moderating effects of technologically turbulent environment in platform-based product development. Our findings suggest that in a high technologically turbulent environment, some management practices have more impact on product platform competency, such as the important role of the existence of a champion in improving the reusability of subsystems, the continuity of platform-based product development team in compatibility of subsystem interfaces, and the design knowledge dissemination across a range of derivative products and the existence of a champion in extensibility of platform-based products. However, some of these findings are contrary to previous studies. For instance, Rochlin et al. (1998) and Akgun and Lynn (2002) suggest that a stable team may not be necessary under highly turbulent environments. We emphasize the importance of such continuity of platform-based product development team especially in a high technologically turbulent environment. Kahn et al. (2006) argue that in a highly turbulent environment, too much formalization may potentially stymie the new product development in terms of innovative ideas and speed. However, such negative moderating effects are not found in the context of platform-based product development. Therefore, the recommendations provided by previous research in the context of individual product development may not be applicable in platform-based product development.

### 7.2.2 Contributions and implications to practitioners

The results obtained from this study have several clear indications on how to manage platform-based product development. These management practices also known as the success factors in platform-based product development in popular management writings, include formalized platform-based product development process, design knowledge dissemination across platform-based products, continuity of platform-based product development team and existence of a champion in platform-based product development. The three elements of product platform competency: the reusability of subsystems, compatibility of subsystem interfaces and extensibility of platform-based products are affected by the aforementioned factors.

Our empirical study has several important implications to managers:

(1) Senior management should encourage and ensure that team members, who participate in the development of one product, continue their roles in another product based on the same platform. Our finding shows that such approach has the highest impact on achieving a higher level of reusability of the platform subsystems and compatibility of subsystem interfaces, among all the four management practices we examined in our study. In addition, this practice will obviously increase the extensibility of platform-based products, and most importantly it can reduce the average development cycle time. In a high technologically turbulent environment, such practice is even more important in order to reach a high level of compatibility design of subsystem interfaces.

(2) Companies involved in platform-based product development should follow a formalized development process to increase the reusability and compatibility of their platform subsystems, as well as the extensibility of their product platform. In addition, having a formalized process has a significant effect on reducing the development cycle time, which is even stronger than the impact from the continuity of platform-based product development team.

(3) Our results also suggest that companies should create an environment which facilitates the dissemination of design know-how among different development teams developing products based on the same platform. This approach is not only beneficial to the reusability and compatibility of their platform subsystems,

but it also influences the product platform extensibility. The impact is even larger in a high technologically turbulent environment.

(4) Employing an experienced product champion in platform-based product development is another popular approach to improve the reusability of platform subsystems. Surprisingly, such approach may not have a clear effect on improving the level of compatibility and extensibility of platform-based products as compared to the other three management practices. But we have to highlight its importance in a high technologically turbulent environment, where champions are found to help development teams achieve high platform extensibility, as shown in Table 6.1. Further more, such a practice has a significant effect in reducing the average development cost of derivative products.

(5) Our study proposed and validated the concept of product platform competency, which has a direct effect on both platform cost efficiency and platform cycle time efficiency, and its impact is even stronger than some other practices we mentioned above, such as the existence of a champion in platform-based product development and the continuity of platform-based product development team. Therefore, instead of thinking of reducing the cost and cycle time in platform-based product development, firms may also try the direct means to enhance their product platform competency, such as the roles of the four management practices we found in our study.

By ensuring the management work is undertaken correctly and efficiently, managers may increase the chances of launching their platform-based products successfully. Most importantly, managers need to take these management practices from an integrated perspective rather than individually, as these factors are unlikely to be sufficient individually to ensure the success of each platform-based product (Johne and Snelson, 1988).

However, as stated by Loch (2000), no one best practice exists in new product development. Companies need to adapt to specific environments to survive in today’s fierce competition. Johne and Snelson (1988) claimed that technological turbulence analysis is the fundamental drive for product innovation. In contrast, based on our empirical findings, a technologically turbulent environment neither has as many interaction effects with related management practices as we expected, nor has direct effects on the final product platform performance. But this cannot be interpreted as technological turbulence being not important to the companies who develop platform-based products. On the contrary, we need to regard this as a new challenge confronted by the companies before they decide to leverage the platform approach. It requires higher capabilities of companies to forecast the technological turbulence ahead and choose the correct technology at the beginning rather than in the middle of developing their derivative products. Because once the base platform is designed, it is neither cheap nor easy to make a radical change unless a new one is developed. In other words, it highlights the importance of initial product platform planning. According to Handerson and Clark (1990, pp.14), "the emergence of a new technology is usually a period of considerable confusion. There is little agreement about what the major subsystems of the product should be or how they should be put together". Such period usually evolves over a longer time before the emergence of a dominant design, because acquiring and applying such architecture innovation may be quite difficult for established firms (Handerson and Clark, 1990). But once a dominant design has been accepted, which is equivalent to the acceptance of a particular product architecture, it tends to become an incremental innovation that builds on existing architecture and component knowledge (Handerson and Clark, 1990). Similarly, in platform-based product development, the initial product platform may take the role of the dominant design (i.e. architecture) and the follow-up product development can be viewed as subsequent incremental innovation. That is why the initial product platform takes a long time to develop, but once completed, it can serve as the foundation for rapid development of follow-up products (Meyer and Dalal, 2002). Therefore, we believe that when careful consideration is taken in the initial stage in platform-based product development, the product platform architecture will be more stable, and the derivative products will be developed more efficiently.

## 7.3 Limitations and directions for future research

This study contains several limitations that should be considered when interpreting the findings and some additional research may expand the knowledge of management in platform-based product development.

Firstly, the theoretical framework might not include all possible successful management practices in platform-based product development. Our study was limited to focus on the roles of four key building blocks in platform-based product development deduced from Robert and Ulrich's (1998) platform framework, from selected literature as well as from our field interviews. However, because of the diversity of management practices existing in product development, they are clearly not the only determinants. The attempt to address all or most aspects of success factors in platform-based product development is desirable but not possible within this study. Robertson and Ulrich's (1998)'s platform framework was primarily from a technology perspective and a organization perspective, ignoring the market perspective, by not taking into account that platform-based products often also share a related set of market applications (see e.g. Meyer and Lehnerd, 1997; Farrell and Simpson, 2003). Similarly, our study also focuses on the technical performance of a product platform, i.e. platform cost efficiency and platform cycle time efficiency, without considering market factors. Future investigations may extend the current study's focus and include more independent variables to examine their roles in enhancing platform-based product development performance, especially on the management practices from market aspect.

Secondly, there was not enough data to conduct a thorough moderator analysis by subgroup analysis in LISREL8, as suggested by Song et al. (2005a) and Sharma et al. (1981). Instead, we explored the moderating effects of technological turbulence using hierarchical multiple regression equation to test interaction effects. Future research may include a thorough moderator analysis to verify our results. Moreover, our study did not link the technologically turbulent environment to the four stages of product life cycle explicitly. Future research may examine the differences of product platform competency among these four stages and provide more revealing insights. In addition, responding to what we mentioned above, market turbulence could be another moderator factor of interest to be considered in platform-based product development when the market perspective is included in future research.

Thirdly, the survey sample in our study is restricted to American companies, thereby constraining the generalization of the results to other countries. In addition, our study focuses on the application of product platforms in traditional industries such as computer and electronic products, automobiles and medical equipments and our survey samples are from nonservice firms listed in the *World Business Directory*. However, the concepts and principles of platforms can be extended to services, such as insurance companies (Meyer and DeTore, 2001), media network; studio entertainment; internet and direct marketing (McGrath, 2001). At this point we know little and are unable to examine how well our findings regarding the effects of management practices and product platform competency on final platform performance are applicable in the service sectors. In order to extend the power of platform into services, we further believe that another research focus could be put on an empirical study of the impact of platform management practices on service performance.

Fourthly, we also recognize the limitation that some of our measures might not be able to capture the full domain of the corresponding construct. For example, compatibility of subsystem interfaces is a new concept measured in our research. The reasons some hypotheses (i.e. H2 and H7b) are not supported may also be because we have not measured the compatibility at all levels of the product platform architecture. Future research may provide a more complete measurement. Similarly, the one-item scale for extensibility of platform-based products may also be extended in future study to make the concept measured more accurately.

Finally, our research is limited to the products within the scope of one common platform and the managerial suggestions are on how to improve the product development performance from an already existing platform. However, to get sustained success, continuous renewal of platforms is a must (Meyer and Lehnerd, 1997), as the benefits of leveraging previous development products in current ones will eventually be surpassed by the benefits of redesigning a platform (Jones, 2003). Hence developing and revitalizing product platforms before their derivative products become dated in terms of function and value are essential to companies' success (Meyer, 1997). Therefore when and how to replace an existing platform or renew a new platform could be one additional promising research direction in this area.

## 7.4 Conclusions

In this dissertation, we started from the trends of today's new product development and further studied relevant literature, but found a set of questions which could not be solved by existing literature. For the purpose of answering these research questions, hypotheses were then developed with input from both literature and field studies in companies. Next, to test these hypotheses, a large-scale survey was conducted in the United States. After analyzing the data by the means of structural equation modeling using LISREL 8.7 and hierarchical multiple regression using SPSS 15.0, we provided satisfactory empirical results to support most of the hypotheses. For those hypotheses that were not statistically significant, the possible reasons were also discussed and explained. Finally, we provided the contribution and implications of this research from both academic and managerial point of view. Due to the limitations of this study, we also noticed that pursuit of research in some additional areas would give worthy contributions in the field of platform-based product development management. In sum, we hope to have provided managers involved in platform-based product development with insights based on our empirical results and also hope our findings may provide a basis for further research, leading to a better understanding in the field.

# REFERENCES:

Aggeri, F. and Segrestin, B. (2007). Innovation and Project Development: an Impossible Equation? Lessons from an Innovative Automobile Project Development. *R&D Management* 37(1): 37-47.

Ahire, S.L. and Devaraj, S. (2001). An Empirical Comparison of Statistical Construct Validation Approaches. *IEEE Transactions on Engineering Management* 48: 319-329

Akgun, A.E. and Lynn, G.S. (2002). Antecedents and Consequences of Team Stability on New Product Development Performance. *Journal of Engineering and Technology Management* 19: 263-286.

Aiken, L.S. and West, S.G. (1991). *Multiple Regression: Testing and Interpreting Interactions*. Newburry Park, CA: Sage.

Anderson, J.C. and Gerbing, D.W. (1988). Structural Equation Modeling in Practice: A Review and Recommended Two-Step Approach. *Psychological Bulletin* 103(3): 411-423.

Argote, L. and Epple, D. (1990). Learning Curves in Manufacturing. *Science* 23 February: 920-924.

Astebro, T. and Michela, J.L. (2005). Predictors of the Survival of Innovations. *Journal of Product Innovation Management* 22: 322-335.

Autio, E., Sapienza, H. and Almeida, J. (2000). Effects of Age at the Entry, Knowledge Intensity and Imitability on International Growth. *Academy of Management Journal* 43(5): 909-924.

Ayers, D., Dahlstrom, R. and Skinner, S.J. (1997). An Exploratory Investigation of Organizational Antecedents to New Product Success. *Journal of Marketing Research* 34: 107-116 (February).

Bagozzi, R.P. and Yi. Y. (1988). On the Evaluation of Structural Equation Models. *Academy of Marketing Science* 16(1): 74-94.

Bagozzi, R.P. Yi, Y. and Phillips, L.W. (1991). Assessing Construct Validity in Organizational Research. *Administrative Science Quarterly* 36(3): 421-458.

Balachandra, R. and Friar, J.H. (1997). Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework. *IEEE Transactions on Engineering Management* 44(3): 276-287.

Baldwin, C.Y. and Clark, K.B. (1997). Managing in An Age of Modularity. *Harvard Business Review* 75(5), 84-93.

Baldwin, C.Y. and Clark, K.B. (2000). *Design Rules: The Power of Modularity*. MIT Press, Cambridge, MA.

Barczak, G., Sultan, F. and Hultink, E.J. (2007). Determinants of IT Usage and New

Product Performance. *Journal of Product Innovation Management* 24: 600-613.

Barney, J., Wright, M. and Ketchen, D.J. (2001). The Resource-based View of the Firm: Ten Years After 1991. *Journal of Management* 27: 625-641.

Baron, R.M. and Kenny, D.A. (1986). The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations. *Journal of Personality and Social Psychology* 51(6): 1173-1182.

Bayus, B.L. (1998). An Analysis of Product Lifetimes in A Technologically Dynamic Industry. *Management Science* 44(6): 763-775.

Benedetto, C.A.D. (1999). Indentifying the Key Success Factors in New Product Launch. *Journal of Product Innovation Management* 16: 530-544.

Bentler, P.M. and Bonett, D.G. (1980). Significnace Tests and Goodness-of-Fit in the Analysis of Covariance Structures. *Psychological Bulletin* 88(3): 588-606.

Bhuiyan, F. (2001). *Dynamic Models of Concurrent Engineering Processes and Performance*. Ph.D. dissertation, Department of Mechanical Engineering, McGill University, Montreal.

Bij, H. van der , Song, M. And Weggeman, M. (2003). An Empirical Investigation into the Antecedents of Knowledge Dissemination at the Strategic Business Unit Level. *Journal of Product Innovation Management* 20: 163-179.

Bollen, K.A. (1989). *Structural Equations with Latent Variables*. New York: John Wiley & Sons.

Boomsma, A. (1983). *On The Robustness of LISREL (Maximum Likelihood Estimation) Against Small Sample Size and Nonnormality*. Unpublished Doctoral Dissertation. University of Groningen, The Netherlands.

Brentani, U.de. (2001). Innovative Versus Incremental New Business Services: Different Keys of Achieving Success. *Journal of Product Innovation Management* 18: 172-187.

Brusoni, S., Prencipe, A. and Pavitt, K. (2001). Knowledge Specialization, Organizational Coupling, and the Boundaries of the Firm: Why Do Firms Know More Than They Make? *Administrative Science Quarterly* 46: 597-621.

Bstieler, L. (2005). The Moderating Effect of Environmental Uncertainty on New Product Development and Time Efficiency. *Journal of Product Innovation Management* 22: 267-284.

Burgelman, R.A. (1991). Intraorganizational Ecology of Strategy Making and Organizational Adaptation: Theory and Field Research. *Organization Science* 2: 239–262.

Byrne, M.B. (2001) *Structural Equation Modeling With Amos*. LEA Publishers, Mahwah, NJ.

Carmines, E.G. and McIver, J.P. (1981). Analyzing Models with Unobservable Variables. In G.W. Bohrnstedt and E.F. Borgatta (Eds.), *Social Measurement: Current Issues*. Beverly Hills: SAGE.

Chai, K.H. and Xin, Y. (2006). The Application of New Product Development Tools in Industry: the Case of Singapore. *IEEE Transactions on Engineering Management* 53(4): 543 – 554.

Chatterjee, S., Hadi, A. S. and Price, B. (2000). *Regression Analysis by Example (3rd edition)*. New York: Wiley.

Chen, K.M. and Liu, R.J., (2005). Interfaces Strategies in Modular Product Innovation. *Technovation* 25: 771-782.

Chin, W.W.; Marcolin, B.L. and Newsted, P.R. (2003). A Partial Least Squares Latent Variable Modeling Approach for Measuring Interaction Effects: Results from A monte carlo Simulation Study and Voice Mail Emotion/Adoption Study. *Information Systems Research* 14(2): 189-217.

Christensen, J.F. (1996). Analysing the Technology Base of the Firm: A Multi-dimensional Resource and Competence Perspective, in: *Towards A Competence Theory of The Firm*. Foss, N.J. and Knudsen, C. (eds.), London: Routledge, 111-132.

Churchill, G.A. (1979). A Paradigm for Developing Better Measures of Marketing Constructs. *Journal of Marketing Research* 16(1): 64-73.

Clark, K.B. and Fujimoto, T. (1991). *Product Development Performance Strategy, Organization and Management in the World Auto Industry*. Harvard Business School Press, Boston, MA.

Cohen, J. and Cohen, P. (1983). *Applied Multiple Regression Correlation Analyses for The Behavioral Science (2nd edition).* Hillsdale, NJ: Lawrence Erlbaum.

Cooper, R.G. (1984). New Product Strategies: What Distinguishes the Top Performers? *Journal of Product Innovation Management* 2: 151-164.

Cooper, R.G. (1994). New Products: the Factors that Drive Success. *International Marketing Review* 11(1): 60-76.

Cooper, R.G. (1999). From Experience: The Invisible Success Factors in Product Innovation. *Journal of Product Innovation Management* 16: 115-133.

Cooper, R.G. and Kleinschmidt, E.J. (1985). An Investigation Into the New Product Process: Steps, Deficiencies and Impact. *Journal of Product Innovation Management* 3:71-85.

Cooper, R.G. and Kleinschmidt, E.J. (1987). New Products: What Separates Winners from Losers? *Journal of Product Innovation Management* 4: 169-184.

Cooper, R.G. and Kleinschmidt, E.J. (1993a), New Product Success in the Chemical Industry. *Industrial Marketing Management* 22(2): 85-99.

Cooper, R.G. and Kleinschmidt, E.J. (1993b). Major New Products: What Distinguishes the Winners in the Chemical Industry. *Journal of Product Innovation Management* 10: 90-111

Cooper, R.G. and Kleinschmidt, E.J. (1995). Benchmarking the Firm's Critical Success Factors in New Product Development. *Journal of Product Innovation*

*Management* 12: 374-391.

Cooper, R.G. and Kleinschmidt, E.J. (2007). Winning Business in Product Development: the Critical Success Factors. *Research-Technology Management* May-June: 52-66.

Cormican, K. and O'Sullivan, D. (2004). Auditing Best Practice for Effective Product Innovation Management. *Technovation* 24: 819-829.

Cox, W. (1967). Product Life Cycles as Marketing Models. *Journal of Business* 40: 375-384.

Cristiano, J.J., Liker, J.K. and White, III, C.C. (2000). Customer-Driven Product Development Through Quality Function Deployment in the U.S. and Japan. *Journal of Product Innovation Management* 17(4): 286-308.

Cusumano, M.A. and Nobeoka, K. (1998). *Thinking Beyond Lean*. New York: Free Press.

Cuttance, P. (1987). Issues and Problems in The Application of Structural Equation Models. In P. Cuttance and R. Ecob (Eds.), *Structural Modeling by Example*. New York: Cambridge University Press.

Daft, R.L. and Lengel, R.H. (1986). Organizational Information Requirements, Media Richness and Structural Design. *Management Science* 32(5): 554-571

Dawson, J.F. and Richer, A.W. (2006). Probing Three-way Interactions: The Development and Application of A Slope Difference Test. *Journal of Applied Psychology* 91: 917-926.

D'Aveni, R.A. (1994). *Hypercompetition: Managing The Dynamics of Strategic Maneuvering*. New York: Free Press.

Davidson, J. M., Clamen, A. and Karol, R.A. (1999). Learning From the Best New Product Developers. *Research Technology Management* 42(4): 12-18.

de Vaus, D. (2002). *Analyzing Social Science Data*. London: SAGE.

Dickson, P.R. (1992). Toward a General Theory of Competitive Rationality. *Journal of Marketing* 56(1): 69-84.

Dillman, D.A. (1978). *Mail and Telephone Surveys: the Total Design Method*. New York: Wiley

Eraut, M. (1994). *Developing Professional Knowledge and Competence*. London: Falmer Press.

Eriksen, B. And Mikkelsen, J. (1996). Competitive Advantage and The Concept of Core Competence, in: *Towards A Competence Theory of The Firm*. Foss, N.J. and Knudsen, C. (eds.), London: Routledge, 54-74.

Ernst, H. (2002). Success Factors of New Product Development: A Review of the Empirical Literature. *International Journal of Management Reviews* 4(1): 1-40.

Evans, D.S., Hagiu, A. and Schmalensee, R. (2005). A Survey of the Economic Role of Software Platforms in Computer-based Industries. *CESifo Economic Studies*

51(2-3): 189-224.

Farrell, R.S. and Simpson, T.W. (2003). Product Platform Design to Improve Commonality in Custom Products. *Journal of Intelligent Manufacturing* 14: 541-556.

Feitzinger, E. and Lee, H.L. (1997). Mass Customization At. *Harvard Business Review* January-February: 116-121.

Fiore, C. (2005). *Accelerated Product Development: Combining Lean and Six Sigma for Peak Performance*. New York: Productivity Press.

Fixson, S.K. (2002). *The Multiple Faces of Modularity—An Analysis of A Product Concept for Assembled Hardware Products*. Working Paper, MIT, Cambridge, MA.

Fornell, C. and Larcker, D. (1981). Structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1): 39-50.

Foss, N.J. (1996). Introduction: The Emerging Competence Perspective, in: *Towards A Competence Theory of The Firm*. Foss, N.J. and Knudsen, C. (eds.), London: Routledge, 1-12.

Foss, K and Harmsen, H. (1996). Studies of Key Factors of Product-development Success: A Resource-based Critique and Reinterpretation, in: *Towards A Competence Theory of The Firm*. Foss, N.J. and Knudsen, C. (eds.), London: Routledge, 133-149.

Frazier, P.A., Tix, A.P. and Barron, K.E. (2004). Testing Moderator and Mediator Effects in Counseling Psychology Research. *Journal of Counseling Psychology* 51(1): 115-134.

Fredrickson, J.W. and Iaquinto, A.L. (1989). Inertia and Creeping Rationality in Strategic Decision Processes. *Academy of Management Journal* 32(3): 516-542.

Frost, P.J. and Egri, C.P. (1991). The Political Process of Innovation. In: Staw, B.M., Cummings, L.L. (eds.), *Research in Organizational Behavior*. JAI Press, Greenwich, CT, 229–295.

Forza, C. (2002). Survey Research in Operations Management: a Process-based Perspective. *International Journal of Operations and Production Management* 22(2): 152-194.

Fujimoto, T., Takeishi, A. and Aoshima, Y. (2001) *Business Architecture: Strategic Design of Product, Organiztion, and Processes*. Tokyo: Yuhokaku Press.

Funk, J.L. (2003). The Product Life Cycle Theory and Product Line Management: the Case of Mobile Phones. *IEEE Transactions on Engineering Management* 51(2): 142-152.

Garud, R. and Kumaraswamy, A. (1995). Technological and Organizational Designs for Realizing Economies of Substitution. *Strategic Management Journal* 16 (Special issue): 93-109.

Garud, R. and Nayyar, P.R. (1994). Transformative Capacity: Continual Structuring by Intertemporal Technology Transfer. *Strategic Management Journal* 15(5): 365-385.

Gerbing, D.W. and Anderson, J.C. (1988). An Updated Paradigm for Scale Development Incorporating Unidimensionality and Its Assessment. *Journal of Marketing Research* 25: 186-192.

Grant, R.M. (2005). *Contemporary Strategy Analysis (5th edition)*. Malden/MA, Oxford: Blackwell.

Graves, S.B. (1988). Institutional Ownership and Corporate R&D in the Computer I, *Academy of Management Journal* 31(2): 417-428.

Gray, P. and Meister, D. (2004). Knowledge Sourcing Effectiveness. *Management Science* 50(6): 621-634.

Griffin, A. (1997). The Effect of Project and Process Characteristics on Product Development Cycle Time. *Journal of Marketing Research February* 34(1): 24-35.

Hair, J.F., Anderson, R.E., Tatham, R.L. and Black, W.C. (1998). *Multivariate Data Analysis (Fifth Editions)*. Upper Saddle River, NJ: Prentice-Hall.

Halman, J.I.M., Hofer, A.P. and Vuuren, W.V. (2003). Platform-driven Development of Product Families: Linking Theory with Practice. *Journal of Product Innovation Management* 20: 149-162.

Hamel, G. and Prahalad, C.K. (1994). *Competing for the Future*. Harvard Business School Press, Cambridge, MA.

Hattie, J. (1985). Methodological Review: Assessing Unidimensionality of Tests and Items. *Applied Psychological Measurement* 9: 139–164

Hauser, J.R. (2001). Metrics Thermostat. *Journal of Product Innovation Management* 18(3): 134-153.

Hayes, R.H., Wheelwright, S.C. and Clark, K.B. (1988). *Dynamic Manufacturing: Creating the Learning Organization.* New York: Free Press.

Henderson, R.M. and Clark, K.B. (1990). Architecture Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly* 35: 9-30.

Hitt, M. and Ireland, R.D. (1985). Corporate Distinctive Competence, Strategy, Industry and Performance. *Strategic Management Journal* 6: 273-293.

Hofer, A.P. and Halman, J.I.M. (2005). The Potential of Layout Platforms for Modular Complex Products and Systems. *Journal of Engineering Design* 16(2/April): 253-258.

Hofer, C.W. and Schendel, D. (1978). *Strategy Formulation: Analytical Concepts.* West Publishing, St. Paul, MN.

Howell, J.M., Shea, C.M. and Higgins, C.A. (2005). Champions of Product Innovations: Defining, Developing, and Validating a Measure of Champion Behavior. *Journal of Business Venturing* 20: 641-661.

Hutcheson, G. D. and Sofroniou, N. (1999). *The Multivariate Social Scientist: Introductory Statistics Using Generalized Linear Models*. London: Sage.

Itami, H. and Roehl, T. (1987). *Mobilizing Invisible Assets*. Cambridge, MA: Harvard University Press.

Jandourek, E. (1996). A Model for Platform Development. *Hewlett-Packard Journal* August, article 6:1-18.

Jaworski, B.J. and Kohli, A.K. (1993). Market Orientation: Antecedents and Consequences. *Journal of Marketing* 57: 53-70.

Johne, F.A. and Snelson, P.A. (1988). Success Factors in Product Innovation: A Selective Review of the Literature. *Journal of Product Innovation Management* 5: 114-128.

Jones, N. (2003). Competing after Radical Technological Change: The Significance of Product Line Management Strategy. *Strategic Management Journal* 24: 1265-1287.

Joreskog, K.G. (1969). A General Approach to Confirmatory Maximum Likelihood Factor Analysis. *Psychometrika* 34:183-202.

Joreskog, K.G. and Sorbom, D. (1993). *LISREL 8: Structural Equation Modeling with The SIMPLIS Command Language.* Scientific Software International

Kahn, K.B., Barczak, G. and Moss, R. (2006). Perspective: Establishing An NPD Best Practices Framework. *Journal of Product Innovation Management* 23: 106-116.

Katz, R. (1982). Managing Careers: The Influence of Job and Group Longevity. In: *Career Issues in Human Resource Management*. Katz, R. (Ed.). Englewood Cliffs, NJ: Prentice-Hall, pp. 154-181

Kelloway, E.K. (1998). *Using LISREL for Structural Equation Modeling: A Researcher's Guide.* Thousand Oaks, California: SAGE.

Kenny, D.A., Kashy, D.A. and Bolger, N. (1998). Data Analysis In Social Psychology, in: *The Handbook of Social Osychology (4th ed.)*, Gilbert, D.T., Fiske, S.T. and Lindzey, G.(eds.), New York: Oxford University Press, 233-265.

Kerlinger, Frederick N. (1973). *Foundations of Behavioral Research*. London: Holt, Rinehart and Winston.

Kessler, E.H. and Chakrabarti, A.K. (1999). Speeding Up the Pace of New Product Development. *Journal of Product Innovation Management* 16: 231-247.

Kim, K. and Chhajed, D. (2001). An Experimental Investigation of Valuation Change Due to Commonality in Vertical Product Line Extension. *Journal of Product Innovation Management* 18(4): 219-230.

Kim, J.Y., Wong, V. and Eng, T.Y. (2005). Product Variety Strategy for Improve New Product Development Proficiencies. *Technovation* 25: 1001-1015.

Kleinschmidt, E.J., Brentani, U.D. and Salomo, S. (2007). Performance of Global New Product Development Programs: A Resource-Based View. *Journal of Product Innovation Management* 24: 419-441.

Klein Woolthuis, R., Hillebrand, B., Nooteboom, B. (2005). Trust, Contact and Relationship Development. *Organization Studies* 26(6): 813-840.

Kline, R. B. (1998). *Principles and Practice of Structural Equation Modeling*. NY: Guilford Press.

Koufteros, X., Vonderembse, M. and Jayaram, J. (2005). Internal and External Integration for Product Development: The Contingency Effects of Uncertainty, Equivocality, and Platform Strategy. *Decision Sciences* 36(1): 97-133.

Krishnan,V. and Gupta, S.(2001). Appropriateness and Impact of Platform-based Product Development. *Management Science* 47(1): 52-68.

Lado, A.A and Wilson, M.C. (1994). Human Resource Systems and Sustained Competitive Advantage: A Competency-based Perspective. *Academy of Management Review* 19(4): 699-727.

Langerak, F. Hultink, E.J. and Robben, H.S.J. (2004). The Impact of Market Orientation, Product Advantage, and Launch Proficiency on New Product Performance and Organizational Performance. *Journal of Product Innovation Management* 21: 79-94.

Laurie, D.L., Doz, Y.L. and Sheer, C. P. (2006). Creating New Growth Platforms. *Harvard Business Review* May: 80-90.

Lawson, C. (1999). Towards a Competence Theory of the Region. *Cambridge Journal of Economics* 23(2): 151-166.

Lee, H.L. and Tang, C.S. (1997). Modeling the Costs and Benefits of Delayed Product Differentiation. *Management Science* 43(1), 40-53.

Leech, N.L., Barrett, K.C. and Morgan, G.A. (2005). *SPSS for Intermediate Statistics: Use and Interpretation (2nd edition).* Mahwah, New Jersey: LEA.

Leithhead, B.S. (2000). Product Development Risks. *Internal Auditor* Oct: 59-61.

Leonard-Barton, D. (1992). Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development. *Strategic Management Journal* 13, Special Issue: Strategy Process: Managing Corporate Self-Renewal. (Summer, 1992): 111-125.

Levitt, T. (1965). Exploit the Product Life Cycle. *Harvard Business Review* November-December: 81-96.

Liedtka, J. (1999). Linking Competitive Advantage with Communities of Practice. *Journal of Management Inquiry* 8(1): 5-16.

Loch, C. (2000). Tailoring Product Development to Strategy: Case of European Technology Manufacturer. *European Management Journal* 18(3): 246-258.

Lynn, G.S., Simpson, J.T. and Souder, W.E. (1997). Effects of Organizational Learning and Information Processing Behaviors on New Product Success. *Marketing Letters* 8(1): 33-39.

Lynn, G.S.; Skov, R.B. and Abel, K.D. (1999). Practices that Support Team Learning and Their Impact on Speed to Market and New Product Success. *Journal of Product Innovation Management* 16(5): 439-454.

Lynn, G.S.; Reilly, R.R. and Akgun, A.E. (2000). Knowledge Management in New

Product Teams: Practices and Outcomes. *IEEE Transactions on Engineering Management* 47(2): 221-231.

MacCormack, A. and Verganti, R. (2003). Managing The Sources of Uncertainty: Matching Process and Context in Software Development. *Journal of Product Innovation Management* 20(3): 217-232.

Madhavan, R. and Grover, R.(1998). From Embedded Knowledge to Embodied Knowledge: New Product Development as Knowledge Management. *Journal of Marketing*, 62 (4): 1-12.

Markham, S.K. (1998). A Longitudinal Examination of How Champions Influence Others to Support Their Projects. *Journal of Product Innovation Management* 15: 490– 504.

Markham, S.K. and Griffin, A. (1998). The Breakfast of Champion: Associations Between Champions and Product Development Environments, Practices and Performance. *Journal of Product Innovation Management* 15: 436-454.

Martin, M.V. and Ishii. K. (1996). *Design for Variety: A Methodology for Understanding the Costs of Product Proliferation.* Proceedings of the 1996 ASME Design Engineering Technical Conference and Computers in Engineering Conference. August 18-22, 1996. Irvine, California.

Maruyama, G.M. (1998). *Basics of Structural Equation Modeling*. Thousand Oaks, California: SAGE.

McDonough, E.F.III. (2000). Investigation of Factors Contributing to The Success of Cross-functional Teams. *Journal of Product Innovation Management* 17: 221-235.

McGrath, M.E. (2001). *Product Strategy for High Technology Companies (2nd edition).* McGraw-Hill.

Meyer, M.H. (1997). Revitalize Your Product Lines through Continuous Platform Renewal. *Research Technology Management* 40(2): 17-28.

Meyer, M.H., Anzani, A. and Walsh, G. (2005). Organizational Change for Enterprise Growth. *Research Technology Management* 48(6): 48-56.

Meyer, M.H. and Dalal, D. (2002). Managing Platform Architectures and Manufacturing Processes for Nonassembled Products. *Journal of Product Innovation Management* 19: 277-293.

Meyer, M.H. and Detore, A. (2001). Perspective: Creating A Platform-based Approach for Developing New Services. *Journal of Product Innovation Management* 18: 188-204.

Meyer, M.H. and Lehnerd, A.P. (1997). *The Power of Product Platform—Building Value and Cost Leadership*. Free Press, New York.

Meyer, M.H. and Lehnerd, A. (2004). Modular Platforms and Innovation Strategy, in: Katz, R. (Eds.), *The Human Side of Managing Technological Innovation*. Oxford University Press, New York, pp. 655-674.

Meyer, M.H. and Lopez, L. (1995). Technology Strategy in a Software Products

Company. *Journal of Product Innovation Management* 12(4): 294-306.

Meyer M.H. and Mugge, P.C. (2001). Make Platform Innovation Drive Enterprise Growth. *Research Technology Management* January-February: 25-39.

Meyer. M.H and Seliger. R. (1998). Product Platforms in Software Development. *Sloan Management Review* 40: 61-74.

Meyer, M.H., Tertzakian, P. and Utterback, J.M. (1997). Metrics for Managing Research and Development in the Context of the Product Family. *Management Science* 43(1): 88-111.

Meyer, M.H. and Utterback, J.M. (1993). The Product Family and The Dynamics of Core Capability. *Sloan Management Review* 34(3): 29-47.

Mikkola, J.H. and Gassmann, O. (2003). Managing modularity of product architecture: toward an integrated theory. *IEEE Transactions on Engineering Management* 50 (2), 204-218.

Mills, J.; Platts, K.; Bourne, M. and Richards, H. (2002). *Competing through competences.* United Kingdom: Cambridge University Press

Mills, J. and Platts, K. (2003). Competence and Resource Architectures. International *Journal of Operations & Production Management* 23(9): 977-994.

Mintzberg, H. (1990). Strategy Formation: Schools of Thought, in: Frederickson, J.W. (Eds.) *Perspective on Strategic Management*, New York: Harper & Row.

Montoya-Weiss, M.M. and Calantone, R. (1994). Determinants of New Product Performance: A Review and Meta-Analysis. *Journal of Product Innovation Management* 11: 397-417.

Moore, G.A. (1991). *Crossing the Chasm: Marketing and Selling Technology Products to Mainstream Customers*. New York: HarperBusiness.

Moorman, C. and Miner, A.S. (1997). The Impact of Organizational Memory on New Product Performance and Creativity. *Journal of Marketing Research* 34(1) Special Issue on Innovation and New Products (Feb., 1997): 91-106

Moriarty, R.T. and Kosnik, T.J. (1989). High-tech Marketing: Concepts, Continuity, and Change. *Sloan Management Review* 30(4): 7-17.

Muffatto, M. and Roveda, M. (2000). Developing Product Platforms: Analysis of The Development Process. *Technovation* 20: 617-630.

Nobeoka, K. and Cusumano, M. (1997). Multi-project Strategy and Sales Growth: The Benefits of Rapid Design Transfer in New Product Development. *Strategic Management Journal* 18(3), 169-186.

Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science* 5(1): 14 – 37.

Nunnally, J.C. (1978). *Psychometric Theory (2nd edition.).* New York: McGraw-Hill.

Paladino, A. (2007). Investigating the Drivers of Innovation and New Product Success: A Comparison of Strategic Orientations. *Journal of Product Innovation*

*Management* 24(6): 534-553.

Pavitt, K. (1991). Key Characteristics of the Large Innovating Firm. *British Journal of Management* 2: 41-50.

Peteraf, M.A. and Barney, J.B. (2003). Unraveling the Resource-Based Tangle. *Managerial and Decision Economies* 24(4): 309-323.

Petersen, K.J., Handfield, R.B. and Ragatz, G.L. (2003). A Model of Supplier Integration into New Product Development. *Journal of Product Innovation Management* 20: 284-299.

Pillai, R, Schriesheim, C.A. and Williams, E.S. (1999). Fairness Perceptions and Trust as Mediators for Transformational and Transactional Leadership: A Two-Sample Study. *Journal of Management* 25(6): 897-933.

Polli, R. and Cook, V. (1969). Validity of the Product Life Cycle. *Journal of Business* 42: 385-400.

Porter, M.E. (1980). *Competitive Strategy: Technique for Analyzing Industries and Competitors*. New York: Free Press.

Porter, M.E. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance*. New York: Free Press.

Prahalad, C.K. and Hamel, G. (1990). The Core Competence of the Corporation. *Harvard Business Review* May-June: 79-91

Raykov, T. and Marcoulides, G.A. (2000). *A First Course in Structural Equation Modeling.* New Jersey: LEA.

Raz, T., Shenhar, A.J. and Dvir, D. (2002). Risk Management, Project Success, and Technological Uncertainty. *R&D Management* 32(2): 101-109.

Riek, R.F. (2001). From Experience: Capturing Hard-won NPD Lessons in Checklists. *Journal of Product Innovation Management* 18: 301-313.

Robertson, D. and Ulrich, K. (1998). Planning For Product Platforms. *Sloan Management Review* 39 (4): 19-31.

Rochlin, G., La Porte, T. and Karlene, H.R. (1998). The Self-designing High-reliability Organization: Aircraft Carrier Flight Operations at Sea. *Naval War College Review* 51: 97-113.

Rosenau, M.C., Griffin, A.J., Anscheutz, N. and Castellion, G. (eds.) (1996). *PDMA Handbook on New Product Development*. New York: John Wiley and Sons.

Rothenberger, M.A., Dooley, K.J., Kulkami, U.R. and Nada, N. (2003). Strategies for Software Reuse: A Principal Component Analysis of Reuse Practices. *IEEE Transactions on Software Engineering* 29(4): 825-837.

Rothwell, R. and Gardiner, P. (1990). Robustness and Product Design Families, in: Oakley, M. (Eds.), *Design Management: a Handbook of Issues and Methods*. Basil Blackwell, Cambridge, MA., USA, pp. 279-292.

Salomo, S., Weise, J. and Gemunden, H.G. (2007). NPD Planning Activities and

Innovation Performance: The Mediating Role of Process Management and the Moderating Effect of Product Innovativeness. *Journal of Product Innovation Management* 24: 285-302.

Sanchez, R. (1995). Strategic Flexibility in Product Competition. *Strategic Management Journal* summer special issue 16: 135-159.

Sanchez, R. (2000). Product and Process Architectures in the Management of Knowledge Resources, in Robertson P.L., and Foss N.J. (eds.), *Resources Technology, and Strategy: Explorations in the Resource-Based Perspective.* Routledge, London: 100-122.

Sanchez, R. (2004). Creating Modular Platforms for Strategic Flexibility. *Design Management Review* winter: 58-67.

Sanchez, R. and Collins, R.P. (2001). Competing—and Learning—in Modular Markets. *Long Range Planning* 34(6): 645-667.

Sanchez, R. and Mahoney, J.T. (1996). Modularity, Flexibility, and Knowledge Management in Product and Organization Design. *Strategic Management Journal* 17(4): 63-76.

Sanderson, S.W. and Uzumeri, M.V. (1995). Managing Product Families: the Case of the Sony Walkman. *Research Policy* 24(5): 761-782.

Sanderson, S.W. and Uzumeri, M. (1997). *Managing Product Families*. Chicago, IL: Irwin.

Sawhney, M.S. (1998). Leveraged High-variety Strategies: from Portfolio Thinking to Platform Thinking. *Academy of Marketing Science* 26(1): 54-61.

Schilling, M.A. (2000). Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity. *Academy of Management Review* 25(2): 312-334.

Schwab, D.P. (1980). Construct Validity in Organizational Behavior. *Research in Organizational Behavior* 2: 3–43.

Segars, A.H. (1997). Assessing The Unidimensionality of Measurement: A Paradigm and Illustration within The Context of Information Systems Research. *Omega* 25(1):107-121.

Selznick, P. (1957). *Leadership in Administration*. New York: Harper & Row.

Sharma, S., Durand, R.M. and Gur-Arie, O. (1981). Identification and Analysis of Moderator Variables. *Journal of Marketing Research* 28: 291-300.

Sherman, J.D.; Souder, W.E. and Jenssen, S.A. (2000). Differential Effects of The Primary Forms of Cross-functional Integration on Product Development Cycle Time. *Journal of Product Innovation Management* 17(4): 257-267.

Sherman, J.D., Berkowitz, D. and Souder, W.E. (2005). New Product Development Performance and the Interaction of Cross-Functional Integration and Knowledge Management. *Journal of Product Innovation Management* 22: 399-411.

Siddique, Z. (2006). Product Family Redesign Using a Platform Approach, in: *Product*

*Platform and Product Family Design*. Simpson, T.W., Siddique, Z., Jiao, J.X. (eds.), New York: Springer Science, 359-376.

Simpson, T.W., Siddique, Z. and Jiao, J.X. (2006). Platform-based Product Family Development, in: *Product Platform and Product Family Design*. Simpson, T.W., Siddique, Z., Jiao, J.X. (eds.), New York: Springer Science, 1-15.

Skold, M. and Karlsson, C. (2007). Multibranded Platform Development: A Corporate Strategy with Multimanagerial Challenges. *Journal of Product Innovation Management* 24: 554-566.

Smith, P.G. and Reinertsen, D.G. (1998). *Developing Products in Half the Time* (2nd edition). New York: Van Nostrand Reinhold.

Snow, C.C. and Hrebiniak, L.G. (1980). Strategy, Distinctive Competence, and Organizational Performance. *Administrative Science Quarterly* 25: 317-335.

Song, M., Berends, H. Bij, H. van der and Weggeman, M. (2007). The Effect of IT and Co-location on Knowledge Dissemination. *Journal of Product Innovation Management* 24(1): 52-68.

Song, M., Droge, C., Hanvanich, S. and Calantone, R. (2005a). Marketing and Technology Resource Complementarity: An Analysis of Their Interaction Effect in Two Environmental Contexts. *Strategic Management Journal* 26: 259-276.

Song, M., Bij, H. van der and Weggeman, M. (2005b). Determinants of the Level of Knowledge Application: A Knowledge-Based and Information-Processing Perspective. Journal of Product Innovation Management 22: 430-444.

Song, M. and Montoya-Weiss, M.M. (2001). The Effect of Perceived Technological Uncertainty on Japanese New Product Development. *Academy of Management Journal* 44(1): 61-80.

Song, X.M. and Parry, M.E. (1997). A Cross-national Comparative Study of New Product Development Processes: Japan and the United States. *Journal of Marketing* 61 April: 1-18.

Song, X.M.; Souder, W.E. and Dyer, B. (1997). A Causal Model of the Impact of Skills, Synergy, and Design Sensitivity on New Product Performance. *Journal of Product Innovation Management* 14: 88-101.

Souder, W.E. and Song, X.M. (1997). Contingent Product Design and Marketing Strategies Influencing New Product Success and Failure in U.S. and Japanese Electronics Firms. *Journal of Product Innovation Management* 14(1): 21-34.

Staudt, T.A., Taylor, D. and Bowersox, D.A. (1976). *A Managerial Introduction to Marketing (3rd edition).* Englewood Cliffs, NJ: Prentice-Hall.

Steiger, J. H. (1990). Structural Model Evaluation and Modification: An Interval Estimation Approach. *Multivariate Behavioral Research* 25: 173-180.

Swan, K.S.; Kotabe, M. and Allred, B.B. (2005). Exploring Robust Design Capabilities, Their Role in Creating Global Products, and Their Relationship to Firm Performance. *Journal of Product Innovation Management* 22: 144-164.

Tabrizi, B. and Walleigh, R. (1997). Defining Next-generation: An Inside Look. *Harvard Business Review* November-December: 116-124.

Takeuchi, H. and Nonaka, I. (1986). The New New Product Development Game. *Harvard Business Review* January-February: 137-146.

Tatikonda, M.V. (1999). An Empirical Study of Platform and Derivative Product Development Projects. *Journal of Product Innovation Management* 16: 3-26.

Tatikonda, M.V. and Montoya-Weiss, M.M. (2001). Integrating Operations and Marketing Perspectives of Product Innovation: The Influence of Organizational Process Factors and Capabilities on Development Performance. *Management Science* 47(1): 151-172.

Thieme, R.J., Song, X.M. and Shin, G. (2003). Project Management Characteristics and New Product Survival. *Journal of Product Innovation Management* 20: 104-119.

Thomke, S.H. (1997). The Role of Flexibility in The Development of New Products: An Empirical Study. *Research Policy* 26: 105-119.

Thorelli, H.B. and Burnett, S.C. (1981). The Nature of Product Life Cycles for Industrial Goods Businesses. *Journal of Marketing* 45 (4): 97-108.

Tull, D.S. and Hawkins, D.I. (1987). *Marketing Research: Measurement and Method: a Text with Cases*. New York: Macmillan.

Tushman, M.L. (1979). Work Characteristics and Subunit Communication Structure: A Contingency Analysis. *Administrative Science Quarterly* 24(1):82-97.

Tushman, M.L. and Nadler, D.A. (1978). Information Processing As an Integrating Concept in Organizational Design. *Academy of Management Review* 3: 613-624.

Ulrich, K. (1995). The Role of Product Architecture in the Manufacturing Firm. *Research Policy* 24(3), 419-440.

Ulrich, K.T. and Eppinger, S.D. (2002). *Product Design and Development (3rd Edition)*. New York: McGraw-Hill.

Uzumeri, M.V and Sanderson, S.W. (1995). A Framework for Model and Product Family Competition. *Research Policy* 24: 583-607.

Veenstra, V.S., Halman, J.I.M., Voordijk, J.T. (2006). A methodology for developing product platforms in the specific setting of the house building industry. *Research in Engineering Design* 17(3), 157-173.

Venkatraman, N. (1989). Strategic Orientation of Business Enterprises: the Construct, Dimensionality and Measurement. *Management Science* 35: 942-962.

Vickery, S.K., Droge, C. and Markland, R.E. (1993). Production Competence and Business Strategy: Do They Affect Business Performance? *Decision Sciences* 24(2): 435-455.

Walsh, J.P. and Ungson, G.R. (1991). Organizational Memory. *Academy of Management Review* 16(1): 57-91

Wang, Q., Chai, K.H., Brombacher, A.C. and Halman, J.I.M. (2004). *Managing Risks in Modular Product Development.* 2004 IEEE Intenational Engineering Management conference, 18-21 Oct, 2004, Singapore, Xie, M., Durrani, T.S. and Tang, H.K. (eds.), Stallion Press, pp. 815-819.

Ward, S.C. and Chapman, C.B. (1991). Extending the use of risk analysis in project management. *International Journal of Project Management* 9(2): 117-123.

West, S.G., Aiken, L.S. and Krull, J.L. (1996). Experimental Personality Designs: Analyzing Categorical by Continuous Variable Interactions. *Journal of Personality* 64: 1-49.

Wheelwright, S. and Clark, K. (1992). *Revolutionizing New Product Development*. New York: The Free Press.

Wiemann, J.M. and Backlund, P. (1980). Current Theory and Research In Communicative Competence. *Review of Educational Research* 50(1): 185-199.

Worren, N. Moore, K. and Cardona. P. (2002). Modularity, Strategic Flexibility, and Firm Performance: A Study of the Home Appliance Industry. *Strategic Management Journal* 23:1123–1140.

Xie, J.H., Song, M. and Stringfellow, A. (2003). Antecedents and Consequences of Goal Incongruity on New Product Development in Five Countries: A Marketing View. *Journal of Product Innovation Management* 20: 233-250.

Yap, C.M. and Souder, W.E. (1994). Factors Influencing New Product Success and Failure in Small Entrepreneurial High-Technology Electronics Firms. *Journal of Product Innovation Management* 11: 418-432.

Yin, R. K. (1994). *Case Study Research: Design and Methods*. Thousand Oaks, CA: Sage Publications.

# APPENDIX A: Pre-survey Questionnaire

# A survey on the effect of management strategies on the success of platform-based product development

## Introduction

The purpose of this study is to understand more about the effect of management strategies on the success of platform-based product development. We assure you that your information will be treated confidentially and that we will not reveal your company name, employee names or technologies to anyone.

If you choose to participate in our study and are interested in the outcome of the study, we will send you a research report summarizing the results of our research project.

**For each statement, please indicate the extent to which you agree or disagree with the statement shown as below.**

| | **Strongly Disagree** | | | **Neutral** | | | **Strongly Agree** |
|---|---|---|---|---|---|---|---|
| 1. Product platform is a known concept and applied within our company<br>The term 'product platform' refers to a set of common components, modules, or parts from which a stream of derivative products can be efficiently created and launched. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. Our product platform designs enable us to accommodate several generations of products, which are regarded as one product family | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. Our product platform designs are drawn to accommodate future generations of products, which will be regarded as one product family | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | Yes | No |
|---|---|---|
| Are you willing to participate in a study on the effect of management strategies on the success of platform-based product development? | ☐ | ☐ |

If you are willing to participate in our study, please provide your company's address and the name of your company's R&D-manager or the person in your company responsible for developing platform-based products and monitoring the product platform development within your firm. Within two weeks the questionnaire will be send to your company. **Please complete the contact information or attach a business card.**

CONTACT INFORMATION

Name: ____________________
Organization: ____________________
Address: ____________________
ZIP code: ____________________
State: ____________________
Email: ____________________

**Thank You**

# APPENDIX B: Final Survey Questionnaire

# A Survey of Platform-based Product Development

The purpose of this study is to better understand the effect of management strategies on the success of platform-based product development. **The questionnaire should take less than 20 minutes to complete.** Respondents who participate in the study will receive a summary of the survey's results, which may provide new insights into the application of platform-based product development strategy in your company. All information will be treated confidentially; we will not reveal your company name, employees' names, or technologies.

**Please read these instructions before proceeding**

1. Our questionnaire is targeted at the R&D-manager or the person in your company responsible for developing platform-based products and monitoring the product platform development within your firm.

2. The term 'product platform' refers to a set of common components, modules, or parts from which a stream of derivative products can be efficiently created and launched.

3. Please select **one of the major product platforms currently in your company** from which several products have been derived and commercialized (which are referred to as one **product family**). This product platform is considered representative of your company's platforms.

   **How many products have been derived and commercialized from this platform?** ______

4. Please answer the following questions based on this same product platform. For each statement, please indicate the extent to which you agree or disagree with the statement, as shown below.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Strongly Disagree | Disagree | Slightly Disagree | Neutral | Slightly Agree | Agree | Strongly Agree |

5. **Please answer all questions.** When a precise answer is not possible, please provide your best estimate rather than leaving the answers blank.

## What do you think of the characteristics of the products derived from this platform?

| | Strongly Disagree | | | Neutral | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 1. After the new product requirements were defined, we realize high commonality with the functional modules that were used by previous products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. After the new product design was completed, we realize high commonality with the functional modules that were used by previous products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. We usually follow a design strategy where common functional modules are used in several products derived from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. We reuse a high degree of similar functional modules in different products derived from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | Strongly Disagree | | | Neutral | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 5. We try our best to reuse "on the shelf" functional modules in different products from this platform wherever possible | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6.There is a high degree of standardized system layout of our product architecture from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7.There is a high degree of common interfaces among different products derived from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8.It is very difficult to make changes in modules without redesigning other parts in the existing products from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9.It is quite easy to add new functional modules without changing other parts to develop new derivative products from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10.The interfaces of our existing product architecture from this platform are compatible with many different functional modules | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11.The interfaces of our existing product architecture from this platform are not suitable for future derivative products | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## What do you think of your platform-based process for product development?

| | Strongly Disagree | | | Neutral | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 12.We have a well-defined development process for creating products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 13.There is a well-written document of the process that guides our engineers to develop products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 14.We regularly check the development progress of our products derived from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 15.We monitor the development progress of our products derived from this platform using standard procedures | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 16.We do an exceptionally good job in keeping track of the development progress of derivative products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 17. Our engineers closely follow a process to develop products from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## What do you think of your teams who develop products from this platform?

| | Strongly Disagree | | | Neutral | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 18. From inception through launch, the same team was accountable for a series of products derived from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 19. From the beginning to the end, the same team was responsible for several products derived from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20.Department managers who were on the team remained on it from one product to another based on this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 21.Team members who were on the team remained on it from one product to another based on this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## What do you think of your knowledge sharing among your development teams?

| | Strongly Disagree | | Neutral | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 22.The level of knowledge shared and disseminated is high among our different product development teams from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 23.There are a lot of informal “hall talks” concerning our technology development tactics or strategies among our different product development teams from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 24.Data on technology development are disseminated at all levels among our different product development teams from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 25.Our different product development teams from this common platform periodically circulate documents (e.g., reports, newsletters) that provide new information and/or knowledge | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 26.We do not communicate information internally about successful technology development across all the products derived from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 27.We freely communicate information internally about unsuccessful technology development across all the products derived from this common platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## What do you think of the champion’s behavior in your product development from this platform?

| | Strongly Disagree | | Neutral | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 28.There was a champion who showed tenacity in overcoming obstacles in our product development from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 29.There was a champion who continued to be involved with the design until it was implemented in our product development from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 30.There was a champion who knocked down barriers to the design in our product development from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 31.There was a champion who persisted in the face of adversity in our product development from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 32.There was a champion who stuck with the objectives despite experiencing negative outcomes in our product development from this platform | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## What do you think of the technological development in your industry?

| | Strongly Disagree | | Neutral | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 33.The technology in our industry is changing rapidly | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 34.Technological changes provide big opportunities in our industry | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 35.It is very difficult to forecast where the technology in our industry will be in the next 2-3 years | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 36.Technological development in our industry is a major part of our products | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Based on your estimation, what do you think of your platform performance in terms of R&D costs?

| | Strongly Disagree | | Neutral | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 37. Compared to our competitors, the average R&D costs of all the products from this platform were much higher than **our competitor's costs** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 38. Compared to our original projected costs, the average R&D costs of all the products from this platform were much less than **our projected costs** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 39. Compared to the R&D cost of the first product from this platform, the average R&D costs of the follow-up derivative products from this platform were much less than the first product (Definition: The follow-up derivative products refer to all the products that have been derived and commercialized from this platform excluding the first product) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Based on your estimation, what do you think of your platform performance in terms of cycle time?

| | Strongly Disagree | | Neutral | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|
| 40. Compared to our competitors, the average development cycle time of all the products from this platform was much longer than **our competitor's cycle time** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 41. Compared to our original planned cycle time, the average development cycle time of all the products from this platform was far shorter than **our planned cycle time** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 42. Compared to the development cycle time of the first product from this platform, the average development cycle time of the follow-up derivative products from this platform was far shorter than the first product (The follow-up derivative products refer to all the products that have been derived and commercialized from this platform excluding the first product.) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Please tell us about your company in general….

| | | | | |
|---|---|---|---|---|
| Number of full-time employees in your division/strategic business unit | ☐ <100 | ☐ 100-499 | ☐ 500-1,000 | ☐ >1,000 |
| What is your R&D expenditure as a percentage of sales? | ☐ <2% | ☐ 2%~5% | ☐ 5%~10% | ☐ >10% |
| What were the annual sales of your business unit last year (approximately)? | $______________________,000 | | | |
| Which industry is your company in? | ☐ Industrial Machinery & Equipment | ☐ Electronic Parts & Equipment | ☐ Communications Equipment | ☐ Software Product |
| | ☐ Computers & Peripheral Equipment | ☐ Motor Vehicles & Motor Vehicle Parts | ☐ Chemicals & Allied Products | ☐ Medical, Dental & Hospital Equipment |
| | ☐ Others (Please specify) | | | |

**Thank you for your thoughtful cooperation.**