Globally Distributed Product Development
Role of Complexity in the What, Where and How

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This dissertation is dedicated to my parents, Kate and Claud Makumbe
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Pedzisayi O. Makumbe

Submitted to the Engineering Systems Division on 29 August 2008 in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Engineering Systems at the Massachusetts Institute of Technology

Abstract

This dissertation presents findings on four elements of the relationship between Global Product Development or Globally distributed Product Development (GPD) and product complexity. I examine this relationship in the context of medical, industrial and electronic equipment developed for American companies outside each development program’s home-country. In the first study, I use multinomial logistics models and find that product complexity, specificity, strategic importance and designing firm’s capability are directly related to the modes of global product development. These modes are namely global partnerships, captive offshoring and global outsourcing. The more complex products are developed through global partnerships or captive offshores, while the less complex products are globally outsourced. However, the difference in complexity among the three modes varies by region when I divide the world into emerging and mature regions. It is largest in emerging regions and statistically non-significant in mature regions. In the second study, I investigate factors that drive product development to different countries around the world. Using negative binomial models, I find that market size, national capability and number of engineering graduates are directly related to the amount of product development in a particular country, while market growth rate and labor cost are not. I also find that as product complexity increases, the importance of the national capability as a location advantage increases, and that national and firm capability are statistically related to each other. In the third study on host national culture, I find that national culture influences the internal team dynamics, but not necessarily where product development is eventually located. Finally, I qualitatively characterize the global product development strategy, organization structure, processes and people, and gather some recommended coordination practices. These include modularizing, not only the product, but the process as well to allow closed-loop monitoring in order to ensure that design expectations were perceived as intended.

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Now faith is the substance of things hoped, the evidence of things not seen

*Hebrews 11 vs. 1 (KJV)*
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Cogito ergo sum

-René Descartes
Table of contents

1 INTRODUCTION AND OVERVIEW ................................................................. 15
  1.1 MOTIVATION ........................................................................................ 15
  1.2 DEFINITION OF GLOBAL PRODUCT DEVELOPMENT .................. 16
    1.2.1 Ties to International Research and Development research ... 17
    1.2.2 Ties to Multinational Corporations research .................. 19
  1.3 HOW THESIS FITS IN THE DIALOGUE .............................................. 19
  1.4 DESCRIPTION OF THESIS DOCUMENT .............................................. 20
  1.5 REFERENCES ....................................................................................... 22

2 BEYOND OUTSOURCING: ROLE OF COMPLEXITY IN GLOBAL PRODUCT
   DEVELOPMENT ......................................................................................... 23
  2.1 INTRODUCTION .................................................................................... 23
    2.1.1 Importance of choosing the right mode of GPD for different modules 24
    2.1.2 Structure of this chapter ............................................................ 25
  2.2 REVIEW OF RELATED LITERATURE .................................................. 26
    2.2.1 Complexity in engineering systems and product development ... 26
    2.2.1.1 Engineering systems view of complexity ......................... 26
    2.2.1.2 Product development view of complexity ....................... 27
    2.2.2 Factors influencing make or buy decisions ................................ 28
      2.2.2.1 Complexity ................................................................. 28
      2.2.2.2 Physical asset specificity ............................................ 28
      2.2.2.3 Capability ................................................................. 29
      2.2.2.4 Uncertainty and opportunism ..................................... 29
      2.2.2.5 Importance to strategy ............................................. 29
      2.2.2.6 Other important factors .......................................... 30
      2.2.2.7 Discussion about factors influencing make or buy decisions 30
    2.2.3 Modes of globally distributed product development ............ 30
      2.2.3.1 Captive offshoring .................................................. 31
      2.2.3.2 Global outsourcing .................................................. 31
      2.2.3.3 Global partnership .................................................. 31
    2.2.4 Literature summary and room for contribution ..................... 32
  2.3 RESEARCH PROTOCOL ................................................................. 32
    2.3.1 Phase I: Exploratory research ................................................... 32
      2.3.1.1 Phase I: Case selection process .................................. 33
    2.3.2 Phase I: Data collection process ............................................. 33
    2.3.3 Phase II: Multiple embedded case studies ......................... 34
      2.3.3.1 Phase II: Case selection process .................................. 34
      2.3.3.2 Phase II: Data collection processes ............................ 34
  2.4 EXPLORATORY FINDINGS: COMPLEXITY DEFINITION AND HYPOTHESES ... 35
    2.4.1 Definition of complexity ......................................................... 36
    2.4.2 Hypotheses ................................................................. 37
  2.5 DATA FOR THE MULTINOMIAL LOGISTICS MODEL ....................... 40
    2.5.1 Dependent variable ............................................................... 40
    2.5.2 Measuring complexity as an independent variable ............... 40
      2.5.2.1 Number of parts ...................................................... 41
      2.5.2.2 Technological novelty .............................................. 42
    2.5.3 Other independent variables ................................................ 43
    2.5.4 Summary of data about each module ................................... 44
  2.6 MULTINOMIAL LOGISTICS MODEL ANALYSIS AND RESULTS .......... 45
    2.6.1 Background to logistic regression ......................................... 45
    2.6.2 Hypotheses tests ............................................................... 46
      2.6.2.1 Designer's technological capability ................................ 46
      2.6.2.2 Worldwide hypotheses tests results ............................ 49
      2.6.2.3 Mature regions hypotheses tests results ....................... 53
      2.6.2.4 Emerging regions hypotheses tests results .................... 55
<table>
<thead>
<tr>
<th></th>
<th>ALL REFERENCES</th>
<th>168</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>APPENDIX A: MODULE-LEVEL DATA COLLECTION TEMPLATE</td>
<td>178</td>
</tr>
<tr>
<td>9</td>
<td>APPENDIX B: DEFINITION OF STATISTICAL TERMS</td>
<td>180</td>
</tr>
</tbody>
</table>
List of figures
Figure 1.1: Comparison of generic product development processes ..................................... 18
Figure 2.1: Tally of module complexity dimensions mentions ........................................... 37
Figure 2.2: Tally of important factors that influence GPD modes ........................................ 38
Figure 2.3: Illustration of the decomposition of a complex product .................................... 41
Figure 2.4: Know-why, know-how or both ........................................................................... 48
Figure 3.1: Tally of mentions of each location advantage in global product development ......... 78
Figure 3.2: Plot of the dependent variable distribution .......................................................... 90
Figure 4.1: Partial regression plot of number of modules and cultural distance .................... 115
Figure 4.2: Partial correlation plot of number of complex modules and cultural distance .......... 116
Figure 4.3: A tally of statements on cultural issues in global product development ............... 119
Figure 5.1: Results on technology strategy: Know-why, know-how or both ......................... 133
Figure 5.2: Product positioning strategy ............................................................................. 135
Figure 5.3: Management coordination practices ................................................................... 138
Figure 5.4: Supplemental coordination mechanisms .............................................................. 143
Figure 5.5: Characteristics of people successful in GPD ....................................................... 147
Figure 6.1: Pictorial summary of findings on modes and product characteristics .................. 159
List of tables

Table 2.1: Interviewees and their ranks ................................................................. 36
Table 2.2: Technological novelty scale .................................................................... 42
Table 2.3: Coordination scale .................................................................................. 43
Table 2.4: Example summarizing data gathered about each module.......................... 44
Table 2.5: Summary of data gathered about each country ....................................... 44
Table 2.6: Worldwide: Multinomial logistic model results ....................................... 52
Table 2.7: Mature regions: Multinomial logistic model results .................................. 54
Table 2.8: Emerging regions: Multinomial logistic model results ................................ 56
Table 3.1: List of companies in the study ................................................................... 76
Table 3.2: Interviewees and their ranks .................................................................... 76
Table 3.3: Databases used in triangulating independent variables .............................. 81
Table 3.4: Correlations among IMF, WB and UNCTAD as sources of market size ...... 83
Table 3.5: Correlations among NSF, OECD and UNESCO sources of the number of
engineering graduates ............................................................................................... 85
Table 3.6: Correlations among engineering wages from the ILO ............................... 88
Table 3.7: Correlations among manufacturing and engineering wages from ILO and BLS 
.................................................................................................................................................. 88
Table 3.8: Deviance of dependent variable distribution ............................................. 91
Table 3.9: Tests of mean equality across modes of global product development .......... 92
Table 3.10: Location advantage hypotheses tests results ......................................... 94
Table 3.11: Model 1 Parameters correlation matrix .................................................... 95
Table 3.12: Model 2 Parameters correlation matrix .................................................... 95
Table 3.13: Robust complexity test equality of means .............................................. 96
Table 3.14: Chi-Squared Test of Independence ..................................................... 97
Table 4.1: Hofstede and Hofstede (2005) Cultural Dimensions of National Culture .... 110
Table 4.2: Partial correlations of culture distance and global product development ....... 117
Table 5.1: Interviewees and their ranks ................................................................. 132
List of equations

Equation 2-1: Overarching multinomial logistic model ................................................................. 40
Equation 2-2: Converting real number of parts into a 5-point scale ............................................ 41
Equation 2-3: S-shaped logistic function ......................................................................................... 45
Equation 2-4: Logarithm of odds ratio (logit) linear function of module characteristics ............. 45
Equation 2-5: Odds ratio as a linear function of module characteristics ...................................... 46
Equation 2-6: New probability as a function of a change in module characteristic and old probability ................................................................................................................................. 50
Equation 3-1: Model of location advantages in global product development .............................. 79
Equation 3-2: Calculation of the national capability ................................................................. 89
Equation 3-3: One form of the specification of the negative binomial distribution ................... 91
Equation 4-1: Definition of cultural distance ................................................................................. 114
1 Introduction and overview
In this chapter, I introduce this study of global product development with a focus on four main topics:

- The role of product complexity, specificity, strategic importance and designer’s capability in influencing the chosen mode of global product development
- The key location advantages in global product development, and the moderating role of product complexity
- The relationship between national culture and likelihood of product development, and the moderating role of complexity in that relationship
- A set of recommended practices for handing coordination in global product development.

Section 1.1 provides the motivation behind the study from both academic and practice perspectives. Section 1.2 defines global product development in detail and briefly outlines how global product development research is related to international research and development, and multinational corporations’ research. Section 1.3 outlines the role of this thesis in the on-going dialogue while section 1.4 introduces each of the four stand-alone chapters.

1.1 Motivation
The phenomenon behind this work is best captured by the title of Thomas Friedman’s New York Times best seller: The World is Flat (Friedman, 2005). This flatness of the world permeated the manufacturing of complex products over the last decade and resulted in several benefits such as reduced costs, access to large labor pools and access to growing foreign markets. It appears that the next frontier of “world flatness” is the product development process of such complex products.

This conjecture is supported by the observation that a great many companies have implemented globally distributed product development operations in the past few years. These companies include Boeing, which developed the Boeing 787 with 43 partners at 135 sites in 9 countries (Gates, 2005); General Electric, which wrote “increasingly,
products used in developing markets will be designed by local teams who understand their application” (General Electric, 2005; p. 10); and Toyota, which globally developed the 2006 Camry at 4 regional centers (i.e., United States, Australia, Japan and other Asia -- Thailand, China and Taiwan) sharing one set of engineering drawings (Toyota Motor Corporation, 2006). Such examples extend to the electronics industry, medical device industry, and beyond as found during this study.

Practical challenges motivating this research were revealed through conversations with product development leaders developing these complex products, especially leaders developing large electro-mechanical products. At an operational level, coordination is one of the biggest challenges given the time zone differences, cultural differences and sometimes disparate information technology systems. However, globalization provides real opportunities and companies are experimenting with ways of building and running global product development operations. Thus research in global product development may help practitioners improve global product development operations as well as the final products from such operations.

From an academic point of view, literature in global product development is in its nascent stages. A large amount of global product development academic understanding is borrowed from international research and development. However, the two are different. For example, product development has more routine jobs, more inter-unit dependence and coordination, and research and development is more concerned with the creation of scientific knowledge (Leifer & Triscari, 1987). Thus there are opportunities for contribution to the literature since “the necessities of science, compared with the needs of engineering and development, entail different managerial problems”(von Zedtwitz & Gassman, 2000; p. 571).

1.2 Definition of global product development
Global Product Development or Globally distributed Product Development (GPD) is defined as a “single, coordinated, product development operation that includes distributed teams in more than one country utilizing a fully digital and connected collaborative product development process”(Eppinger & Chitkara, 2006; p. 23). These extensive GPD
operations largely occur in three modes namely; global partnerships, where the firm partners globally to develop certain modules; captive offshoring, where the firm’s foreign subsidiary develops the module; and global outsourcing, where the firm simply engages a global supplier to develop a specified module. In addition to this module-specific globalization of product development, firms are also engaged in the globalization of phases or tasks (see Figure 1.1) of the product development process. For instance, product testing or modeling might be captive offshored or outsourced to countries such as India, while the module design ownership remains in the US. The focus of this research is on the module-specific GPD with some qualitative discussion about the phase-specific global product development. Module-specific GPD seems preferred among companies advanced in GPD efforts.

1.2.1 Ties to International Research and Development research

From the typical set of organizational functions, research and development is possibly closest to product development. However, the two are different. Research is “primarily concerned with expanding scientific knowledge and assessing its feasibility” (Leifer & Triscari, 1987; p. 71), while development is focused “on the application of the technology base to operational requirements with the intent of bringing a new (or modified) product into existence” (ibid). Thus technology is first created in the international research and development organization and then transferred to the product development organization through a technology transfer process (Eldred & McGrath, 1997).

Despite these differences, I found it useful to be informed by the international research and development research in this work. As a result, I will use the international R&D literature together with the product development literature as literature jump-off points.

On one hand, several international R&D taxonomies have been proposed (e.g., Chiesa, 1996; Medcof, 1997). From this plentitude of taxonomies, von Zedtwitz & Gassman’s (2000) work is most relevant to the work in this dissertation. They identified four archetypes of research and development, namely national treasure, market-driven, technology-driven and global research and development. These archetypes are identified by the relationship between research tasks and development tasks as driven by markets.
and technology at each R&D location. Most relevant to this work is the global archetype, which they characterized as having "distributed research as well as development" (p. 581).

On the other hand, Ulrich and Eppinger (2004) define product development as a process that starts with product planning and ends with production ramp-up, as shown in Figure 1.1A. In another classic text, Clark and Fujimoto (1991) define product development as a process that starts with concept development and ends with process engineering, as shown in Figure 1.1B. The two definitions of product development overlap significantly, as indicated in Figure 1.1 below.

Figure 1.1: Comparison of generic product development processes

According to Ulrich et al. (2004), product planning involves an assessment of the strategy, technology and marketing objectives of the company producing the product. The concept development phase involves identification of technical possibilities and market needs, creation of product concepts, and evaluation of those concepts against the market needs. The architecture is created during the system design phase, and competing objectives are reconciled and early prototypes created for industrial designers. This phase is followed by the detail design phase where the parts’ specifications, such as weight, mass, and materials, are specified. Detail design is followed by testing and refinement of prototypes and pre-production versions of the product. In the production ramp-up phase, the product is produced as ready for market but with the intention of fine-tuning the production system and training the workforce.
1.2.2 Ties to Multinational Corporations research

The Multinational Corporations (MNC) research is more holistic than both the product development literature and the international R&D research. MNC literature includes all organizational functions such as sales, marketing, and finance. My interests in this dissertation are more specific to the product development process.

In the definition of GPD above, *global* refers to the involvement of several countries in a single product development process. The global entities developing a product module get involved to differing extents. Researchers from the international management tradition have classified enterprises with overseas operations into multinational, global, international and transnational enterprises based on the level of involvement of overseas subsidiaries (Bartlett & Ghoshal, 1989). By *global* these researchers refer to enterprises that “are centralized and globally scaled, whose subsidiaries simply implement parent company strategies and whose knowledge is created and stored at the center” (Bartlett & Ghoshal, 1989; p 65). Clearly, this nomenclature does not transfer well to the product development context. Depending on whether the global operation is a partnership, captive or outsourced, global product development practice is much more involved than implied by this definition of *global*. As used in this thesis, the term *global* is closest to *transnational* in international management literature where foreign units are interdependent and specialized so that each unit provides expertise in developing a particular component of a product, and the knowledge created is jointly shared by the enterprise developing the engineering system (Bartlett & Ghoshal, 1989; Nohria & Ghoshal, 1997).

1.3 How thesis fits in the dialogue

This dissertation brings an understanding of global product development, product development, international R&D, and multinational corporations’ literatures together and strictly focuses on the global product development process. The work contributes towards both global product development academic literature, and towards global product development practice. Academic contributions are largely covered in Chapters 2, Chapter 3 and Chapter 4, while Chapter 5 focuses on recommended practices in product development as a contribution towards the practice of global product development.
1.4 Description of thesis document

The dissertation is organized into four self-contained chapters sandwiched between an introduction and a conclusion. The chapters are unified by the role complexity in global product development. This chapter introduces the entire study.

Chapter 2 goes beyond outsourcing, and discusses how the nature of the product influences the relationship between the host global entity and the American parent firm. The nature of the product is operationalized as the product complexity, specificity, designing firm’s capability and module strategic importance. The nature of the relationship is operationalized as captive offshore, global outsource or global partnership as defined up. In the chapter, I use a multinomial logistic model to examine the relationship between the type of relationship and the nature of the product. Thus the model estimates the probability of module-development through one of the three modes of GPD based on the properties of the module.

Chapter 3 discusses the location advantage in global product development, that is, I investigate factors that attract product development to specific countries. Using a negative binomial model, I examine the importance of market size, market growth rate, national capability, number of engineering graduates and labor cost in influencing location choices in GPD. I also investigate the moderating role of complexity, and the relationship between national capability and firm capability.

Chapter 4 is an investigation of whether national culture influences the likelihood that modules will be developed in a country. I operationalize culture using (Hofstede, 1984) indices and likelihood of product development as the number of modules developed in that country. To test the relationship between the two, I use partial correlations.

Chapter 5 is a characterization of the globally distributed product organization and a collection of some recommended practices in coordination. In addition to the information processing view, I add the people dimension to the characterization since GPD organizations cross different organizational and national cultures.
Finally, Chapter 6 summarizes the entire study, and suggests areas for further research.
1.5 References


2 Beyond outsourcing: Role of complexity in global product development

2.1 Introduction

Today’s complex products involve several different technologies which are changing at a rapid pace to the extent that no individual manufacturer can effectively develop and manufacture all product modules in-house, and at a single location (Fine & Whitney, 1996; p. 101). At the same time, the world is increasingly connected (Friedman, 2005) and foreign economies are growing briskly. As a result, many leading American firms are actively engaged in globally distributed product development. These companies range from leading industrial equipment manufacturers such as Caterpillar and GE Energy, through medical device manufacturers such as Philips Medical Devices and Perkin Elmer to electronics manufacturers such as Cisco and Flextronics. These leading firms are engaging countries as varied as China, India, Sweden, Germany, Brazil and Israel in their product development efforts. Thus current product development operations are truly and increasingly global.

Global Product Development or Globally distributed Product Development (GPD) is defined as a “single, coordinated, product development operation that includes distributed teams in more than one country utilizing a fully digital and connected collaborative product development process’’(Eppinger & Chitkara, 2006, p. 23). GPD largely occurs in three modes, namely global partnerships, where the firm partners globally to develop certain modules; captive offshoring, where the firm’s foreign subsidiary develops the module; and global outsourcing where the firm engages a global supplier to develop a module on its behalf. In addition to this module-specific modularization of product development, firms are also engaged in the globalization of the product development phases. For instance, product testing or modeling might be captive offshored to countries such as India while the module design ownership remains in the US or Germany. The focus of this chapter is on the module-specific global product development with some qualitative discussion of the phase-specific global product development. Module-specific
global product development seems common among companies advanced in their global product development efforts.

There are several enablers and drivers fuelling the growth of globally distributed product development. Information technologies such as Computer Aided Design (CAD) and Computer Aided Engineering (CAE) have been one of the biggest enablers in developing complex products such as magnetic resonance imaging machines, hydrogen powertrains or radiometry modules globally. The drivers include quest for lower costs, improved efficiency, access to markets, and access to technology (Tripathy & Eppinger, 2007). As scientifically documented, most of these drivers are borrowed from international research and development, and in cases where researchers focused on product development, the research has largely been conducted in the form of self-assessment surveys administered to senior executives.

Since GPD literature is in its nascent stages, it is not clear which modes of GPD are best suited for developing the different types of complex product modules. Thus once a product system, e.g. the elevator system, is broken down into the entrances, machines, controls, drives, etc, it is not clear how product development leaders can best choose the appropriate mode of GPD to best serve their GPD operations. It is plausible that complexity might play a key role in this critical discussion; hence I intend to primarily investigate how complexity influences the mode of globally distributed product development in this chapter. In addition to complexity, I will investigate how the strategic importance of that module, the designer’s capability and specificity of the module influence the mode of global product development. I define specificity as the uniqueness of a module i.e. the lower the percentage of off-the-shelf parts in a module, the more specific the module. Additionally, I take the perspective of a large American firm throughout the entire study.

2.1.1 Importance of choosing the right mode of GPD for different modules

Insights into how complexity and the other variables influence the GPD mode decisions provide several benefits to practitioners and to the academic understanding of globally distributed product development. From an academic point of view, this chapter builds on
the make or buy literature in three distinct ways: Firstly, I focus my attention on product development (vs. manufacturing), secondly I put emphasis on the global aspect of global product development, and thirdly I include global partnership as a third option to the dichotomous make or buy. Additionally, I empirically assess my definition of complexity, and investigate its role in choosing the mode of global product development.

From a practitioner’s point of view, knowing when to either develop in-house or integrate suppliers and partners has largely been credited with the success of the Japanese automobile industry (Clark & Fujimoto, 1991). Mishra & Sinha (2008) argued that global product development projects outperform local product development as uncertainty increases, thus using the write mode for the globalization increases the chances of success. Additionally, global partnering or global outsourcing the right modules allows the firm to focus on core tasks (Prahalad & Hammel, 1990; Zhao & Calantone, 2003). Using Cummins as an example, Venkatesan (1992) argued that such a skill is necessary for survival in the engineering of complex product systems.

2.1.2 Structure of this chapter
Section 2.2 discusses related literature. More specifically, the section reviews the role of complexity in engineering systems and product development, and then discusses several factors from transaction cost and resource based views of the firm that influence the make or buy decision in large engineering firms. The section also extensively discusses the three modes of globally distributed product development. Section 2.3 discusses my two-phased research protocol. The first phase describes the qualitative research which allowed me to define constructs, and explore the usefulness of constructs from the make or buy literature in the context of global product development. The second phase describes how I quantitatively measured constructs from the first phase. Section 2.4 covers the operationalization of complexity, and hypotheses relating modes of GPD to complexity. Section 2.5 describes how I measured data for the quantitative model, and section 2.6 covers the hypotheses test results. Section 2.7 discusses implications of the study for product development leaders, section 2.8 summarizes the study and section 2.9 highlights some key academic contributions from the study. Finally, section 2.10 suggests opportunities for further research along this stream of work and 2.11 lists key references.
2.2 Review of related literature
There are two major streams of literature pertinent to my exposition of the role of complexity in globally distributed product development: the complexity literature and the make or buy literature. I will first review the complexity literature focusing on its definitions and role in product development, followed by the make or buy literature focusing on factors that serve as key drivers in the make or buy decision. Lastly, I will provide details on the modes of globally distributed product development that I introduced above.

2.2.1 Complexity in engineering systems and product development
Complexity is widely discussed in the study of complex systems to the extent that Sussman (2003) lists 21 different definitions of complexity. Being interested in large complex product systems, I am going to review complexity definitions from engineering systems and product development points of view. The engineering systems view provides a holistic picture, while the more limited product development view allows focus on the product development process.

2.2.1.1 Engineering systems view of complexity
In his seminal work, Simon (1962) talked about a complex system as one “made up of a large number of parts that have many interactions” (Simon, 1998; p. 184). This definition is grounded in the nature of complex systems as hierarchical and nearly decomposable. As Alexander (1964) argued, the creation of such manmade complex systems is fundamentally a distributed problem solving process, and this view ties into my perspective of product development as a problem solving process (Wheelwright & Clark, 1992). Thus, Simon’s view of complexity is a useful way of thinking about complexity in product development.

More recently, research in engineering systems has emphasized three types of complexity, namely structural, behavioral and interface complexity. Firstly, Moses (2004), proposes that a system is structurally complex if it has numerous components whose interactions, interconnections or interdependence are difficult to describe (p. 9). Along the same lines,
Maier & Rechtin (2000) define complexity as “a measure of the numbers and types of interrelationships among the system elements” (p. 293). Secondly, a system is behaviorally complex if its external behavior is difficult to predict (Moses, 2004, p. 9; Sussman, 2003). Thirdly, a system has complex interfaces if it has numerous components such as knobs, making the system difficult to operate (Moses, 2004; p. 9). From these three types of complexity, I am primarily interested in structural complexity because structural complexity addresses the architectural properties of the complex product system (Ulrich, 1995).

2.2.1.2 Product development view of complexity
Kim & Wilemon (2003) found that definitions of complexity varied widely among product development researchers. Using the development project as the unit of analysis, Clark & Fujimoto (1991) defined complexity as the product content, variety and innovation (p.150). Coming from the same research context, Cusumano & Nobeoka (1990) defined complexity differently as “the number and type of components designed anew in a single project” (p.4). Tatikonda & Rosenthal (2000) added to the list of definitions of project complexity and defined project complexity as “the nature, quantity, and magnitude of organizational subtasks and subtask interactions posed by the project” (p. 78)

At the module level, Novak & Eppinger (2001) defined complexity as the number of parts to be produced, parts coupling and the degree of product novelty (p. 189). On the other hand, Griffin (1997) separated product complexity from product newness (novelty) and defined complexity as “the number of functions of a product” (p. 24), and Murmann (1994) added to the list of definitions defining complexity as the number of parts in the product.

Thus, there is no widely used definition of complexity in product development, particularly at the module level. The amount of difference is even more pronounced at the operational level of complexity. As a result, I will employ grounded theory (Glaser & Strauss, 1967) during the first portion of my quantitative empirical work to empirically
assess the definition of complexity in the context of globally distributed product development.

2.2.2 Factors influencing make or buy decisions
Largely popular in the 1980s and early 1990s, the make or buy literature focused on the type of products manufactured in-house, and products manufactured by suppliers (Canez et al., 2000; Klein, 2004). Except for Ulrich & Ellison (2005) who extended the make-buy decision beyond manufacturing to include product design, this stream of research largely focused on product manufacturing. My primary focus is in product development which is fundamentally different from manufacturing (Clark & Fujimoto, 1991; Thomke & Fujimoto, 2000; Wheelwright & Clark, 1992). Nonetheless, factors driving the make or buy decision tend to be grounded in the transaction cost theory of the firm (Coase, 1937; Williamson, 1981) and the resource based view of the firm (Penrose, 1959; Wernerfelt, 1995). These views are fundamental to organizations hence they might help us understand why manufacturers chose modes of GPD. Since the individual schools of thought are not sufficient on their own (Langlois & Robertson, 1989), I will review important factors from both schools of thought as an attempt to explain my observations in global product development more holistically.

2.2.2.1 Complexity
Using government contracts in the aerospace industry, Masten (1984) found that complexity increased the chances of internally sourcing a product. He measured complexity using a relative 3-point scale. Unfortunately, he did not explicitly define complexity and used complexity as a surrogate for uncertainty. In the automobile industry, Novak and Eppinger (2001) refined the definition and measurement of complexity. They defined complexity as the number of parts, interactions and technological novelty of the product, and measured complexity using functional properties of the modules before converting the values into a zero through one scale. They found that producers tended to manufacture complex products in-house.

2.2.2.2 Physical asset specificity
As Montverde & Teece (1982) found in the automobile industry, Pisano (1990) found in R&D in the biotechnology industry, and Masten (1984) found in the aerospace industry,
the more specific the production assets were to a firm, the more likely were associated
products produced in-house. Recently, researchers have extended the notion of specific
assets to describe site, physical and human capital as well as firm-specific knowledge
(Klein, 2004).

2.2.2.3 Capability
Firms also choose to develop products in-house in order to preserve capability (Espino-
Rodriguez & Padron-Robaina, 2006; Prahalad & Hammel, 1990; Teece et al., 1997) or
develop products through one of the external means in order to access capability (Ulrich
& Ellison, 2005). Thus capability can drive a firm to source production internally or
externally.

2.2.2.4 Uncertainty and opportunism
There is general agreement in the make-or-buy literature that uncertain product
transactions are largely done in-house because of the difficulty associated with evaluating
suppliers or specifying contracts (Walker & Weber, 1984; Williamson, 1975). By
“uncertain product transactions” I mean product-related exchanges which can not be fully
specified contractually. That is, there is uncertainty associated with the final product to be
delivered at a future date. In-house production reduces opportunism which is often
associated with high uncertainty and high asset specificity (Grossman & Hart, 1986;
Ouchi, 1980). From a high uncertainty point of view, opportunism arises when one party
in a product-related exchange takes advantage of an incomplete contract (due to bounded
rationality) to the detriment of the other party. From a high asset specificity point of view,
the supplier might hold-up the buyer if the buyer has no alternative choice (Sheffi, 2005).
Both uncertainty and opportunism are potentially associated with complexity in globally
distributed product development.

2.2.2.5 Importance to strategy
Importance to strategy is another factor which drives the make or buy decision. Some
modules are strategically “indispensable to the company’s competitive positioning”
(Venkatesan, 1992; p. 101), hence they are produced in-house. The strategic importance
is largely driven by the product differentiation in the market, and projected industry
trends etc (Welch & Nayak, 1992).
2.2.2.6 Other important factors
There are several other factors that might drive firms towards different modes of GPD. For instance, outsourcing might help firms minimize financial investments (Tayles & Drury, 2001), vary supply to match demand variability (Tripathy & Eppinger, 2007), or take advantage of external economies of scale (Cachon & Harker, 2002). Firms might have historical patterns driving them one way or the other (Nelson & Winter, 1982), or they might be influenced by their national culture (Belderbos, 2003; McLaren, 2000). The list is potentially endless. However, I believe the factors reviewed above are the most important to global product development.

2.2.2.7 Discussion about factors influencing make or buy decisions
There are three major limitations to my application of the make-or-buy factors to global product development. Firstly, I am strictly discussing product development in this chapter which is different from manufacturing. For instance, in manufacturing shipping is usually done in bulk while prototypes in product development are usually air-shipped in small quantities. Secondly, factors do not consider the global aspect of product development. The global aspect potentially has an impact on, for example uncertainty. The perception of uncertainty continents apart is much higher than when engineers are a couple of feet apart. Finally, the make or buy choice is binary. From my experiences there is a third mode of product development, namely global partnership. As a result, I will conduct some exploratory research (Stebbins, 2001) to narrow down the dozen or so factors discussed above to a few critical ones which I will use to run more rigorous multinomial logistics models. Before moving onto the exploratory research, the three modes of globally distributed product development are described in detail below.

2.2.3 Modes of globally distributed product development
The international R&D and multinational corporations’ research streams have distinct taxonomies that were informative as I explored useful ways of thinking about modes of global product development. In international R&D, researchers have defined different types of international research and development. For instance, von Zedtwitz & Gassman (2000) defined four forms of international R&D namely national treasure R&D, technology driven R&D, market driven R&D and global R&D; and Kuemmerle (1997a) defined home-base augmenting and home-base exploiting forms of R&D. In the
multinational corporation research Doz et al (2001) classified firms as international, transnational, global and multinational. Along the same lines, researchers in product development focused on two main organizational forms namely global outsourcing and captive offshoring. These two modes seem particularly useful in GPD; hence I will describe each and introduce global partnerships as a third mode of globally distributed product development.

2.2.3.1 Captive offshoring
In captive offshoring, the manufacturer owns the product development resources in the foreign country (Eppinger & Chitkara, 2006; p. 26). Dyer (2000) uses the term vertical integration to describe similar phenomenon but neglecting the location. He describes vertical integration as when the manufacturer “produces required input in-house and controls both the buying and the sourcing unit” (p. 24). Other researchers, such as Anderson et al. (2008), neglect whether the development was done by different firms or the same firm. Given these and many other different definitions, I am going to adopt Eppinger & Chitkara’s (2006) definition of captive offshoring as when the manufacturer develops its own products outside the program-home country.

2.2.3.2 Global outsourcing
In global outsourcing, the product development is done in a foreign country by separate “unaffiliated suppliers or outside engineering firms” (Cusumano & Nobeoka, 1990; p. 29). Researchers generally agree on the usage of the term “outsourcing” For instance, Anderson et al. (2008) use the term to refer to “relationships between organizations in different firms” (p. 261), and (Dyer, 2000) maintains that the manufacturer does not have an ownership stake in the supplier in an outsourcing arrangement.

2.2.3.3 Global partnership
Global partnerships are based on long term relationships, an ownership stake, joint venture or strategic alliance (Cusumano & Nobeoka, 1990; Dyer, 2000) in product development. Likewise, the reasons for global partnerships are a mix of reasons supporting captive offshoring and global outsourcing. Part of my objective in this chapter, is to clearly differentiate the three modes of globally distributed product development, and when they are commonly employed in GPD.
2.2.4 Literature summary and room for contribution
I have reviewed the complexity and make or buy streams of research as they relate to global product development. From the complexity literature, I found that there is no consensus on the definition of complexity in product development. Definitions ranged from the simplistic number of parts in a product to the number parts, product novelty and amount of interactions among the components in the product. As result, I proposed to do some exploratory research to empirically assess my definition of complexity in globally distributed product development.

Through reviewing the make or buy literature, I discovered several important factors from the transaction cost and resource based views of the firm which might help explain why firms engage certain modes of GPD over others. However, these factors were articulated in the context of studying manufacturing which is different from product development. As a result, I proposed to use exploratory research to find a subset of these factors important in choosing among the modes in globally distributed product development.

2.3 Research protocol
My research protocol consisted of two major phases. The first phase was largely exploratory and qualitative while the second phase consisted of several embedded case studies where I obtained data for quantitative analysis. The qualitative methods allowed me to “capture a more complete, holistic, and contextual portrayal of the units under study” (Jick, 1979; p. 603). The bulk of my work focused on the quantitative methods as a way of investigating hunches, and anecdotes that emerged from systematic analyses of qualitative interviews.

2.3.1 Phase I: Exploratory research
According to Eisenhardt (1989) and Stebbins (2001) exploratory research yields empirically valid hypotheses and definitions. Thus my goal in this phase was to empirically and systematically define module complexity in globally distributed product development, and unearth critical factors that influence mode decisions in GPD. I started the process guided by the literature reviewed above, collected data in the field, analyzed
the data, improved on the theory and repeated the process until I had a stable definition of complexity and a stable set of hypotheses (Glaser & Strauss, 1967).

2.3.1.1 Phase I: Case selection process
The population consisted of product development leaders who had recently developed or were developing complex electromechanical systems globally. Such leaders included product development leadership working on medical equipment such as magnetic resonance imaging machines, industrial equipment such as earth moving equipment, electronic equipment such as servers. From that population, I used quota sampling and interviewed product development leaders working at large American companies with the goal of increasing the diversity of opinions in my data set. In order to avoid generalized superfluous discussions, my interviews were centered on specific modules developed outside the program-home country.

Initially, I spent the first 500 hours working as a global product development engineer on a clean-energy, high-tech globally distributed product development project that involved four companies in three countries across Europe and North America. In the spirit of quota sampling, I then broadened my set of interviewees to chief technology officers, directors and vice presidents of engineering from 17 other companies involved in the development of electromechanical systems. These 17 were chosen to test and extend the replicability of findings from the initial case study.

By largely focusing on large American companies I controlled for possible firm size and national culture influencing the modes of global product development.

2.3.2 Phase I: Data collection process
The data collection process began with open-ended interviews on factors that influenced modes of globally distributed product development. Each interview was done and recorded in person, and lasted from 30 minutes to 3 hours depending on the seniority of the interviewee and stage in the research process. The average interview lasted for an hour. The interviews tended to be longer during the early phases of the research, and as the responses converged, I used semi-structured interviews which tended to be shorter.
The interview data was supplemented by observation data as I worked on the globally distributed product development project for 500 hours.

Most of the product development leaders were located in the US and a few were located in Europe and Asia though they all worked for American companies. All in all I conducted over 80 interviews from 18 different large American companies over a period of 15 months including the initial 500 hours spent working on a GPD project.

2.3.3 Phase II: Multiple embedded case studies
My overarching goal during this second phase was to obtain quantitative data for statistical analysis with the goal of explaining how complexity and other module characteristics influence the mode of globally distributed product development. These characteristics were derived from the literature, and phase one qualitative research described above.

2.3.3.1 Phase II: Case selection process
The population consisted of tier 1 electromechanical modules i.e. subsystems at the first level of decomposition from the entire product system product (see Figure 2.3), developed by large American firms outside their program-home country. From this entire population, I used the quota sampling method (Campbell & Stanley, 1967; Yin, 2002) to sample a diverse modules-dataset. Beyond the first company, I limited each company to at most 12 modules, and the yield rate was about 6 modules per company.

2.3.3.2 Phase II: Data collection processes
The data collection process was partially combined with qualitative data gathering described above. After establishing contact at the company, I set up a phone or in-person conversation with the different product development leaders (usually the director of engineering or the vice president of engineering). At the beginning of each interaction, I described the two phases of my research, and spent a good amount of time qualitatively discussing global product development. The last 15 minutes or so of each interaction were devoted to explaining my quantitative data requirements. I gathered this module level data using a data template in which rows represented the modules and columns represented characteristics of the module such as specificity, number of parts etc (see
Appendix A). In order to make sure that I got the right data, I helped each respondent provide data for a single row i.e. one module. This allowed the respondents to ask questions and get clarification on any of the data items represented by the columns.

After explaining the quantitative data requirements in detail, I gave each respondent a week to complete the rest of the data template. In addition to the template, I gave them a document (see Appendix A) which explained each column of data to serve as a reference. Most respondents returned the data template within a couple of days. All in all, I obtained 156 modules. From the 156 modules, I could not use 38 modules. Of the 38 modules, 23 were missing data, and the remaining 15 were decomposed at tier 2 and tier 3 hence I could not use the data since my decomposition was at tier 1.

In addition to the module level data, I gathered the development location data using databases available through subscription. In particular, I gathered data on the labor cost in the countries that were involved in development of any of the modules. Details on how I collected location-level data are covered in Chapter 3.

2.4 Exploratory findings: Complexity definition and hypotheses
In this section I present findings from the exploratory phase of my research. Table 2.1 lists interviewee ranks. In order to capture both technical and business constructs in globally distributed product development, I interviewed across the entire product development organization ranks from engineers to the heads of product development.
Table 2.1: Interviewees and their ranks

<table>
<thead>
<tr>
<th>Interviewee rank</th>
<th>Number of interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Vice Presidents or Chief Technology Officers</td>
<td>3</td>
</tr>
<tr>
<td>Vice Presidents</td>
<td>3</td>
</tr>
<tr>
<td>Directors</td>
<td>19</td>
</tr>
<tr>
<td>Chief Engineers or General Managers</td>
<td>5</td>
</tr>
<tr>
<td>Managers</td>
<td>11</td>
</tr>
<tr>
<td>Supervisors</td>
<td>14</td>
</tr>
<tr>
<td>Engineers</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
</tr>
</tbody>
</table>

2.4.1 Definition of complexity

In empirically assessing the definition of complexity, I asked interviewees what made the module they had developed complex from a global product development point of view. Responses are exemplified by statements such as “The complexity here is largely in the technology...we don’t know what the results will be and we can’t afford a lot of testing” or “its mostly in the parts and interactions,” from some of the engineers in the study. The frequency with which the various dimensions were mentioned is represented in Figure 2.1 below. Based on these results and the definitions of complexity reviewed in Section 2.2.1, I defined module complexity as the technological novelty, number of parts and amount of interactions associated with the module. This definition is an extension on Simon’s (1962, 1998) definition of complexity and similar to Klibanoff & Novak (2003) and Novak & Eppinger (2001) definitions of complexity.
2.4.2 Hypotheses

I coded the interviews to find critical factors that influence modes of globally distributed product development. For instance, statements such as “smaller low value components i.e. dollar value, it’s better for a company to develop those than us” and “we tend to outsource the less critical subsystems” were coded as indicating that strategic importance was an important factor in making mode decisions in GPD. “Unique but integral modules such as the grain tank are developed here” and “some off-the-shelf components - we have high voltage parts in the defibrillator which are off the shelf” were coded as specificity. “We keep interfaces and customer-facing components in-house” and “complex activities tend to be kept in-house” were coded as complexity. Finally, statements such as “Where expertise doesn’t exist, we keep in-house until we teach a supplier” and “we look around for skill set…” were coded as referring to designing firm’s capability. The frequency with which each factor was mentioned is shown in Figure 2.2.
Based on the tallied results and the literature reviewed above, I derived the following hypotheses about the relationship between complexity, modes of globally distributed product development, and the host development location:

The directionality of the first hypotheses is based on prior research which has argued that complex work is done internally versus externally (e.g. Novak & Eppinger, 2001):

H1: Worldwide (pooling data from emerging and mature regions), an increase in module complexity increases the likelihood of product development through the captive offshore mode relative to the global outsource mode.

The literature is fairly silent on global partnership and complexity. However, from observations during the field study, I hypothesize the following two hypotheses:
H2: Worldwide (pooling data from emerging and mature regions), an increase in module complexity increases the likelihood of product development through the global partnership mode relative to the global outsource mode.

H3: Worldwide (pooling data from emerging and mature regions), an increase in module complexity increases the likelihood of product development through the global partnership mode relative to the captive offshore mode.

Since I do not intuitively expect a difference in the relationship between modes and complexity in GPD done in mature host regions versus worldwide, I hypothesize the same directionality in hypotheses 4 and 5, as in hypotheses 1 and 2. However, mature regions tend to have fairly capable organizations hence the difference between captive offshore and global partnerships might be splitting hairs.

H4: In mature host regions, an increase in module complexity increases the likelihood of product development through the captive offshore mode relative to the global outsource mode.

H5: In mature host regions, an increase in module complexity increases the likelihood of product development through the global partnership mode relative to the global outsource mode.

Likewise, I hypothesize the same directionality in the relationship between complexity and modes of global product development. However, I do expect the relationship to be stronger in favor of captive offshore or global partnership relative to global outsource since firms in emerging regions are generally less capable.

H6: In emerging host regions, an increase in module complexity increases the likelihood of product development through the captive offshore mode relative to the global outsource mode.

H7: In emerging host regions, an increase in module complexity increases the likelihood of product development through the global partnership relative to the global outsource mode.
2.5 Data for the multinomial logistics model

In this model, the module is the unit of analysis. For each module I gathered data on the mode of global product development, complexity, specificity, associated designing firm’s capability and importance of that particular module to firm strategy. The following subsections describe how I measured each of these variables.

Equation 2-1: Overarching multinomial logistic model

\[ Mode = \beta_1 \text{Complexity} + \beta_2 \text{Specificity} + \beta_3 \text{Designer Capability} + \beta_4 \text{Importance to Strategy} \]

2.5.1 Dependent variable

The dependent variable is discrete and the choices are global outsource, global partnership or captive offshore. Using the definitions above, I asked respondents whether the module developed outside the program home-country was developed by a supplier (global outsource), partner (global partnership) or self (captive offshore). However, companies often do design reviews with their suppliers, and in some cases phases of product development (e.g. parts testing) are outsourced. Thus by inferring who developed the module, I am referring to the firm responsible for the module development before systems integration.

2.5.2 Measuring complexity as an independent variable

As systematically shown in Section 2.4.1, complexity in product development has three dimensions namely, number of parts, the technological novelty of the module and amount of interactions associated with each module. As a result, complexity is operationalized as the average of the three dimensions. The following sections explain how I measured each of these dimensions of complexity.
2.5.2.1 Number of parts

To get the number of parts associated with each module, I asked the respondent to give me the number of parts *in* the tier 1 module. As illustrated in Figure 2.3 this number is equivalent to the number of parts at tier 2 level. Since each module can have many small parts, I asked for a number excluding miscellaneous parts such as screws and fixtures.

For example, the number of parts in the left module in Figure 2.3 is 4, while the equivalent value is 3 for the module on the right. In order to compare the number of parts across different product systems, and combine this real number with a scale number from other dimensions of complexity, I converted the number of parts into a 1 through 5 scale using Equation 2-2 (Porter et al., 2006).

**Equation 2-2: Converting real number of parts into a 5-point scale**

$$
\eta = 4 \times \left[ \frac{n - n_{\text{min}}}{n_{\text{max}} - n_{\text{min}}} \right] + 1
$$

where:

- $\eta$ is the converted number of parts as entered into the model
• \( n \) is the number of parts given by a respondent from one company representing one module
• \( n_{\text{max}} \) is the maximum number of parts from all the modules given by a respondent from one company
• \( n_{\text{mmn}} \) is the minimum number of parts from all the modules given by a respondent from one company

2.5.2.2 Technological novelty
In measuring technological novelty, I created the scale shown in Table 2.2. Other measures such as patents (Griliches, 1990) are not applicable in this case since firms rarely patent discoveries from product development (Makumbe, 2006).

<table>
<thead>
<tr>
<th>Level of Newness</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>New to the world</td>
<td>5</td>
</tr>
<tr>
<td>New to my industry worldwide</td>
<td>4</td>
</tr>
<tr>
<td>New to my company worldwide</td>
<td>3</td>
</tr>
<tr>
<td>New to my company locally</td>
<td>2</td>
</tr>
<tr>
<td>Not new at all</td>
<td>1</td>
</tr>
</tbody>
</table>

2.5.2.3 Amount of interactions
Unlike the number of parts in a module, most respondents could not provide the number of interfaces associated with a module. As a result, I used the coordination scale in Table 2.3 to measure the amount of interactions associated with each module. This scale-metric had the advantage that engineering directors and managers had a sense of the amount of coordination that went into developing a given module, and coordination is a reasonable surrogate for the amount of interactions at the module level. Nonetheless, there are many reasons for coordination. As Allen (1977) pointed out, there is coordination “to maintain staff knowledge, or promote creativity” (p.2). As a result, I had to be specific that I was interested in coordination driven by interfaces in the product and not coordination for any other reason. Allen (1977) employed the same strategy by pointing out that he was interested in communication for coordinating work in his studies.
Note that the amount of coordination during the product development process changes, hence the data is biased towards the frequent or more memorable interactions (Reagans et al., 2004; Wasserman & Faust, 1994).

Table 2.3: Coordination scale

<table>
<thead>
<tr>
<th>Level of coordination</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>We completely integrated them, they had to work on the same contract</td>
<td>5</td>
</tr>
<tr>
<td>We actively coordinated them, I had <strong>frequent</strong> meetings</td>
<td>4</td>
</tr>
<tr>
<td>We actively coordinated them, I had <strong>infrequent</strong> meetings</td>
<td>3</td>
</tr>
<tr>
<td>We actively coordinated them, by &quot;copying&quot; them on communications</td>
<td>2</td>
</tr>
<tr>
<td>We encouraged coordination but I did not actively do much</td>
<td>1</td>
</tr>
</tbody>
</table>

2.5.3 Other independent variables

In addition to complexity, I measured specificity, importance to strategy and associated designer’s capability. I operationalized these variables as many researchers have done:

Specificity - I asked respondents for percentage of parts off-the-shelf in the module, and converted those values into a 1 through 5 scale where the higher the number of parts of the shelf, the lower the specificity of the module. For instance, a module with 0 to 10% modules off the shelf had a specificity score of 5; one with 11-20% parts off the shelf had a specificity score of 4; 21-30% specificity score of 3; 31-40% specificity score of 2 and anything above 41% had a specificity score of 1.

Importance to strategy - I measured importance to strategy using a three point scale as judged by the respondents. If the respondent judged that having the manufacturer develop the module was critical to the manufacturer’s strategy, I coded the importance to strategy as 3. If the respondent judged that having the manufacturer develop the module was complimentary but not critical to the manufacturer’s strategy, I coded the importance to strategy as 2. Lastly, if the respondent judged that having the manufacturer develop the module was not necessary to the manufacturer’s strategy, I coded the importance to strategy as 1.
Designer’s capability - I measured the designing firm’s capability using a similar three point scale with unique capability, same as the parent firm’s capability and below parent firm’s capability corresponding to 3, 2 and 1 respectively. The specific values for each designer were judged by the respondents and I converted their values into the 3, 2 and 1 scale for statistical analysis.

2.5.4 Summary of data about each module

For each of the 118 modules, I gathered data as exemplified in Table 2.4.

<table>
<thead>
<tr>
<th>Module Characteristic</th>
<th>Raw Value</th>
<th>Coded Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module name</td>
<td>Ultra Wide Band Transceiver</td>
<td></td>
</tr>
<tr>
<td>GPD mode</td>
<td>Global Outsource</td>
<td>3</td>
</tr>
<tr>
<td>Number of parts</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Technological novelty</td>
<td>New to the world</td>
<td>5</td>
</tr>
<tr>
<td>Interactions</td>
<td>We actively coordinated them, we had frequent meetings</td>
<td>4</td>
</tr>
<tr>
<td>Specificity</td>
<td>0%-10%</td>
<td>5</td>
</tr>
<tr>
<td>Designer's Capability</td>
<td>Unique</td>
<td>3</td>
</tr>
<tr>
<td>Importance to strategy</td>
<td>It's critical to our strategy</td>
<td>3</td>
</tr>
</tbody>
</table>

In addition to the module characteristics, I also recorded location characteristics using databases available through subscription. This information is summarized below in Table 2.5. Chapter 3 explains in detail how I measured each of these variables.

<table>
<thead>
<tr>
<th>Location characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>France</td>
</tr>
<tr>
<td>Number of modules developed</td>
<td>6</td>
</tr>
<tr>
<td>Market size (US$ billion)</td>
<td>2001</td>
</tr>
<tr>
<td>Market growth</td>
<td>1.53</td>
</tr>
<tr>
<td>Number of engineering graduates</td>
<td>43907</td>
</tr>
<tr>
<td>Labor cost (US$/mo.)</td>
<td>3155</td>
</tr>
<tr>
<td>Average national capability</td>
<td>6.76</td>
</tr>
</tbody>
</table>
2.6 Multinomial logistics model analysis and results

2.6.1 Background to logistic regression

In a typical logistic regression, the dependent variable only takes two values which are usually denoted by 0 or 1. Since I have three options in the dependent variable; global partnership, captive offshore, or global outsource; I used a multinomial logistic regression model. The model does not assume linearity of relationship, does not assume homoscedasticity and does not require normally distributed variables like ordinary least squares regression (Garson, 2008b). Nonetheless it requires a linear relationship between logits and independent variables, and independence of observations. I assume the former requirement and my data meets the later requirement.

The model predicts the probability of product development through any of the three modes of global product development as shown in Equation 2-3 (Albright et al., 2004).

Equation 2-3: S-shaped logistic function

\[ \rho_j = \frac{1}{1 + e^{-(\beta_{j0} + \beta_{j1}x_1 + ... + \beta_{jk}x_k)}} \]

Where:

- \( \rho_j \) = probability of global product development through mode \( j \)
- \( x_i \) = independent variable e.g. complexity; \( i = 1, 2..., k \)
- \( \beta_{ji} \) = coefficient of the respective independent variable in mode \( j \); \( i = 0, 1..., k \)

Equation 2-3 can be transformed into a linear function as in Equation 2-4 below:

Equation 2-4: Logarithm of odds ratio (logit) linear function of module characteristics

\[ \ln \left( \frac{\rho_j}{1 - \rho_j} \right) = \beta_{j0} + \beta_{j1}x_1 + ... + \beta_{jk}x_k \]

The logistics model applies the maximum likelihood principle to Equation 2-4 in order to choose asymptotically efficient parameters (Greene, 1997). The principle starts with
arbitrary estimates of $\beta_{ji}$, calculates the log likelihood and adjusts the initial $\beta_{ji}$ estimates in the determined direction and repeats the process until there is negligible change in the log likelihood. The log likelihood reflects how likely one is to observe values of the dependent variable from the observed values of the independents (Garson, 2008b).

Logistics model coefficients are intuitively difficult to interpret. As a result, modelers often transform the coefficients into odds ratios which are defined as the quotient of the probability of an event happening (e.g. being captive offshored) and the probability of the event not happening (i.e. being globally outsourced or captive offshored). Equation 2-5 is a transformation of Equation 2-4. Adopting the practice in the community, I will discuss my results in the form of odds ratios.

**Equation 2-5: Odds ratio as a linear function of module characteristics**

$$\frac{\rho_j}{1-\rho_j} = e^{\beta_{j0} + \beta_{j1}x_1 + \ldots + \beta_{jk}x_k}$$

### 2.6.2 Hypotheses tests

Grouping the hypotheses by location, I am going to test the first set of three hypotheses specific to data from both mature and emerging regions pooled together followed by mature regions hypotheses, and conclude by testing hypotheses specific to emerging regions.

#### 2.6.2.1 Designer’s technological capability

The case processing summary in Table 2.6 shows the number of modules in each mode of global product development. The model uses a total 116 modules because 2 software modules were dropped from the analysis because I am predominantly interested in electromechanical systems.

The likelihood ratio tests table indicates the p-values associated with each of the independent variables. In model 1, the designing firm’s capability is not related to modes of GPD in a statistically significant way. I found this result surprising given that a good
number of my interviews indicated capability as key factor in deciding the mode of
global product development. As a result, I investigated the issue more deeply.

Firm capability in product development can be broken down into know-why, and know-
how. Know-why is the scientific knowledge for developing a given product, while know-
how is the process or systems knowledge for developing the product (Wheelwright &
Clark, 1992).

Armed with this understanding of a firm’s capability, I reanalyzed the qualitative
interviews to gauge the importance of know-why and know-how in global product
development. Statements such as “because they lack systems knowledge, they need
training” and “we had to train them in Failure Mode and Effect Analysis (FMEA)” were
interpreted to mean that suppliers or partners can be trained to build their know-how. One
automotive manager added “emerging technology is different from what we are used to
putting into the vehicle. Some suppliers don’t have automotive background. We work
with companies that know the technology, and help them develop automotive capability.”

On the other hand, firms appeared primarily driven by know-why capability in
globalizing product development. For instance a medical devices manager mentioned,
“We are partners in Norway because they had the technology first...”, and another
director mentioned “We set it up so that we can learn about the technology from Yamaha.
It was one of the most complex jobs.”

From such statements, I tabulated the frequencies of statements indicating that companies
where engaging global product development largely for know-why vs. know-how. The
tally is shown in Figure 2.4
From Figure 2.4 it appears firms engage in global product developed largely for the technological (know-why) capability and when systems/process capability is involved, it is usually combined with technological capability.

As a result I operationalized designer’s technological capability as the interaction variable between designer’s capability and the associated technological component of complexity, and know-how as the product of designer’s capability, and the parts and interfaces portion of complexity. I ran model 2 with designer’s technological capability replacing designer’s capability and the results are shown in Table 2.6. Model 2 is the best-fit model because of the higher chi-squared value, least amount of collinearity and least correlations among variables in the model.
2.6.2.2 Worldwide hypotheses tests results

The results discussion for each set of hypotheses is structured around each of the independent variables. I first present results on complexity, then specificity, importance to strategy and end with designer’s capability:

Complexity - overall, the complexity likelihood ratio test p-value is less than 0.05 (likelihood ratio tests table, row 2, column 3 in Table 2.6) indicating that there is a statistically significant relationship between the mode of global product development and module complexity worldwide.

Since complexity is a statistically significant variable, the odds ratios allow us to specifically investigate the relationship between complexity and the individual modes. Using the global outsource mode as the reference category, Table 2.6 Model 2 indicates that the odds ratio for module complexity \((\exp(\beta_1))\) are 3.61 times in favor of captive offshore, and 6.06 times in favor of global partnership. This means that given the captive offshore and global partnership as alternatives to global outsource, complex modules are likely to be captive offshored but even more likely to be developed through a global partnership relative to a global outsource. On comparing development through a global partnership vs. a captive offshore, the difference between the two is not statistically significant though modules developed through global partnerships tend to be more complex. Thus hypotheses 1 and 2 are supported with a p-value less than 0.01, while hypothesis 3 is not supported.

As an illustration, the probability of being captive offshored \((p_{\text{captive offshore}})\) from our sample is \(\frac{41}{116} = 0.35\) without considering the properties of the modules. Using Equation 2-5, this probability can be expressed in terms of the module characteristics and the odds ratios for a specific model. Thus we can be specific about the change in probability when complexity increases. Since a unit increase in complexity increases the odds ratio of development through the captive offshore mode with respect to global outsource by 260%, the unit increase in complexity yields a new \(p_{\text{captive offshore}} = 0.65\) (using Equation
2-5 and its equivalent transformed into Equation 2-6. Thus the increase in $\rho_{captive\ offshore}$ is 0.30.

Equation 2-6: New probability as a function of a change in module characteristic and old probability

$$\rho_{j_{new}} = (1 - \rho_{j_{new}}) e^{\beta_j \Delta x} \rho_{j_{old}}$$

- Where $\Delta x$ is the change in an independent variable (such as complexity in this example)

Similarly $\rho_{global\ partnership} = 0.17$. A unit increase in complexity increases the odds ratio of development through the global partnership mode relative to the global outsource mode by 6.06. Thus a unit increase in complexity yields a new $\rho_{global\ partnership} = 0.55$. The increase in $\rho_{global\ partnership}$ is 0.38

Specificity - the odds ratio is 80% higher in favor of global partnership and captive offshore modes relative to the global outsource mode. However, they are the same between the two (captive offshore and global partnership). The finding that specificity is the same in modules developed through global partnership or captive offshored is slightly different from current thinking in the literature where specificity is highest in captive offshored modules.

Importance to strategy - Strategically important modules have odds ratios 170% higher in favor of development through the captive offshore mode relative to the global outsource mode, and 290% higher relative to the global partnership mode. This suggests that strategically important modules are likely to be developed through captive offshore rather than through global outsourcing or global partnership. However, there is no statistical difference between global outsource and global partnership.

Designer’s technological capability - Relative to the global outsource mode, odds ratio for the captive offshore mode are 80% lower, and odds for global partnerships are 60% lower. This means that when firms are predominantly looking for technological capability,
they are more likely to engage in the global outsource mode. Global partnerships are preferred where the technology is new and the module is complex, i.e. there is a significant amount of coordination, while the global outsource mode is preferred where the technology is new and there is limited need for coordination. Comparing the captive offshore mode to global partnership, the odds ratio for captive offshore is 50% lower. Thus captive offshore technological capability is not only lower than the global outsourcee’s technological capability; it is also lower than the global partner’s technological capability.
Table 2.6: Worldwide: Multinomial logistics model results

<table>
<thead>
<tr>
<th>Likelihood Ratio Tests</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Complexity</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Importance to Strategy</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Designer's Capability</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Designer's Technological Capability</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chi-Square</td>
<td>60.91</td>
<td>75.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case Processing Summary (N)</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Partnership</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Captive Offshore</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Global Outsource</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Valid</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>Missing</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
<td>118</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complexity exp(β)</td>
<td>1.87** (4.17)</td>
<td>4.66*** (12.75)</td>
<td>0.41** (4.56)</td>
<td>3.61*** (12.00)</td>
<td>6.06*** (14.92)</td>
</tr>
<tr>
<td></td>
<td>Specificity exp(β)</td>
<td>1.58** (5.18)</td>
<td>1.66** (3.85)</td>
<td>0.95 (0.04)</td>
<td>1.81*** (7.18)</td>
<td>1.81** (4.87)</td>
</tr>
<tr>
<td></td>
<td>Importance to Strategy exp(β)</td>
<td>3.07*** (9.20)</td>
<td>0.73 (0.58)</td>
<td>4.22*** (10.07)</td>
<td>2.71** (6.02)</td>
<td>0.69 (0.75)</td>
</tr>
<tr>
<td></td>
<td>Designer's Capability exp(β)</td>
<td>0.69 (1.02)</td>
<td>0.62 (1.17)</td>
<td>1.12 (0.07)</td>
<td>0.21*** (13.17)</td>
<td>0.43* (3.61)</td>
</tr>
<tr>
<td></td>
<td>Designer's Technological Capability exp(β)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>0.49* (2.68)</td>
<td></td>
</tr>
</tbody>
</table>

a = reference category is the global outsource  
b = reference category is the global partnership  
Wald statistic for testing null hypothesis that logit is zero are shown (in parentheses)  
*p < 0.1  **p < 0.05  ***p < 0.01
2.6.2.3 Mature regions hypotheses tests results

As shown in Table 2.7 for Model 4, the likelihood ratio test of complexity is not statistically significant; hence complexity does not serve as a statistically significant driver for differentiating among the modes of global product development in mature regions. As a result, hypotheses 4 and 5 are not statistically significant.

Specificity – The likelihood ratio test of specificity is statistically significant in Model 4. The odds ratio is about 120% higher in favor of global partnerships and captive offshore but about the same between the two modes. These findings are similar to findings from the worldwide findings, except that the odds ratio was 80% higher.

Importance to strategy - In mature regions, I observed the same pattern as for pooled data though the odds ratio is 700% higher for captive offshore relative to global outsource, and 1100% higher relative to global partnership. These values compare to 200% and 300% higher respectively from the worldwide analysis. In general, this implies that firms are much more likely to captive offshore in mature regions.

Designer’s technological capability – The odds ratio of the captive offshore mode is 80% and 70% lower relative to the global outsource and global partnership modes respectively. However, the difference between the captive offshore and the global outsource is much more statistically significant than the difference between captive offshore and global partnership. There is no statistical difference in odds ratios between global partners and global suppliers as driven by technological capability.
### Table 2.7: Mature regions: Multinomial logistic model results

#### Likelihood Ratio Tests

<table>
<thead>
<tr>
<th></th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>0.00</td>
</tr>
<tr>
<td>Complexity</td>
<td>0.08</td>
<td>0.11</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Importance to Strategy</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Designer Capability</td>
<td>0.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Designer's Technological Capability</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Chi-Square</td>
<td>53.25</td>
<td>63.5</td>
</tr>
</tbody>
</table>

#### Model 3

<table>
<thead>
<tr>
<th></th>
<th>Captive Offshore vs. Global Outsource</th>
<th>Global Partnership vs. Global Outsource</th>
<th>Captive Offshore vs. Global Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity</td>
<td>exp(β₁) 0.99 (0.00)</td>
<td>3.34* (3.57)</td>
<td>0.30* (3.52)</td>
</tr>
<tr>
<td>Specificity</td>
<td>exp(β₂) 2.04** (5.39)</td>
<td>2.36** (5.06)</td>
<td>0.87 (0.12)</td>
</tr>
<tr>
<td>Importance to Strategy</td>
<td>exp(β₃) 8.52*** (10.60)</td>
<td>0.7 (0.35)</td>
<td>12.17*** (10.61)</td>
</tr>
<tr>
<td>Designer Capability</td>
<td>exp(β₄) 0.6 (0.98)</td>
<td>0.76 (0.20)</td>
<td>0.79 (0.14)</td>
</tr>
<tr>
<td>Designer's Technological Capability</td>
<td>exp(β₅)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Model 4

<table>
<thead>
<tr>
<th></th>
<th>Captive Offshore vs. Global Outsource</th>
<th>Global Partnership vs. Global Outsource</th>
<th>Captive Offshore vs. Global Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity</td>
<td>exp(β₁) 1.88 (1.11)</td>
<td>4.17** (4.06)</td>
<td>0.45 (1.27)</td>
</tr>
<tr>
<td>Specificity</td>
<td>exp(β₂) 2.23** (6.04)</td>
<td>2.32** (5.00)</td>
<td>0.96 (0.01)</td>
</tr>
<tr>
<td>Importance to Strategy</td>
<td>exp(β₃) 8.04*** (7.59)</td>
<td>0.67 (0.44)</td>
<td>12.04*** (8.80)</td>
</tr>
<tr>
<td>Designer Capability</td>
<td>exp(β₄) 0.63 (0.68)</td>
<td>0.31* (4.12)</td>
<td></td>
</tr>
<tr>
<td>Designer's Technological Capability</td>
<td>exp(β₅)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a = reference category is the global outsource
*b = reference category is the global partnership

Wald statistic for testing null hypothesis that logit is zero are shown (in parentheses)

*p < 0.1  **p < 0.05  ***p < 0.01
2.6.2.4 Emerging regions hypotheses tests results

Based on the likelihood ratio tests in emerging regions, complexity is the key differentiator among the different modes in my model. Since complexity is related to the mode of global product development, I can more deeply analyze how complexity varies with the individual modes of global product development.

In emerging regions I observe behavior similar to the worldwide behavior. A unit increase in complexity increases the odds ratio of being captive offshored by 300%, and increases the odds ratio of being developed through a global partnership by 1000% relative to the global outsource in both cases. These compare to increases of 300% and 500% in the worldwide analysis. The odds ratio for captive offshore vs. global partnership is 60% lower though it is not statistically significant. Thus hypotheses 6 and 7 are statistically significant.

Specificity and strategic importance of the module are not statistically significant drivers of modes of global product development in emerging regions in my model. Perhaps the location plays a more important role than the module in choosing modes in emerging regions. Designer’s technological capability is barely significant with a p-value of 0.08. Removing the non-significant independent variables exaggerates the odds ratios for complexity in the directions discussed above, and increases the designer’s technological capability to p-value = 0.14.
Table 2.8: Emerging regions: Multinomial logistics model results

<table>
<thead>
<tr>
<th></th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Likelihood Ratio Tests</td>
<td>Case Processing Summary (N)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intercept</td>
<td>Complexity</td>
<td>Specificity</td>
</tr>
<tr>
<td></td>
<td>0.73</td>
<td>0.00</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>0.97</td>
<td>0.00</td>
<td>0.43</td>
</tr>
<tr>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Captive Offshore&lt;sup&gt;a&lt;/sup&gt; vs. Global Outsource&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;a&lt;/sup&gt; vs. Global Partnership&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;b&lt;/sup&gt; vs. Global Partnership&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;a&lt;/sup&gt; vs. Global Outsource&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;b&lt;/sup&gt; vs. Global Outsource&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;a&lt;/sup&gt; vs. Global Partnership&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Captive Offshore&lt;sup&gt;b&lt;/sup&gt; vs. Global Partnership&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity</td>
<td>exp(β&lt;sub&gt;1&lt;/sub&gt;) 2.90** (4.21)</td>
<td>7.50*** (8.22)</td>
<td>0.39 (2.10)</td>
<td>4.11** (6.09)</td>
<td>10.87*** (8.91)</td>
<td>0.38 (1.73)</td>
<td></td>
</tr>
<tr>
<td>Specificity</td>
<td>exp(β&lt;sub&gt;2&lt;/sub&gt;) 1.18 (0.25)</td>
<td>1.26 (0.32)</td>
<td>0.93 (0.03)</td>
<td>1.36 (0.81)</td>
<td>1.59 (1.15)</td>
<td>0.86 (0.15)</td>
<td></td>
</tr>
<tr>
<td>Importance to Strategy</td>
<td>exp(β&lt;sub&gt;3&lt;/sub&gt;) 1.51 (0.63)</td>
<td>1.12 (0.03)</td>
<td>1.35 (0.24)</td>
<td>1.36 (0.32)</td>
<td>1.04 (0.00)</td>
<td>1.310 (0.18)</td>
<td></td>
</tr>
<tr>
<td>Designer Capability</td>
<td>exp(β&lt;sub&gt;4&lt;/sub&gt;) 0.92 (0.02)</td>
<td>0.43 (1.18)</td>
<td>2.11 (1.02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designer's Technological Capability</td>
<td>exp(β&lt;sub&gt;5&lt;/sub&gt;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> = reference category is the global outsource  
<sup>b</sup> = reference category is the global partnership  
Wald statistic for testing null hypothesis that logit is zero are shown (in parentheses)  
*p < 0.1  **p < 0.05  ***p<0.01
2.7 Discussion and implications
In this chapter, I extended the make or buy literature to include partnerships, and focused on the *global* aspect of product development by limiting my study to modules developed outside the program home-country. I found new insights that might help product development leaders and engineering managers systemize and improve global product development efforts.

I found that more complex modules are more likely to be developed through global partnerships. This finding is different from the prevailing literature which states that complex work is more likely to be done in-house. I believe this difference is due to the fact that firms often seek technology not available locally when they go abroad, particularly in regions with higher capability. Since complexity is a combination of parts, interactions, and technological novelty, it is logical that global partnerships develop the more complex products. Their technological capability is higher than captive offshores’ technological capability, and their capacity to coordinate is higher than global outsourcees’ capacity to coordinate. Captive offshores might have better capacity to coordinate but not necessarily the technological capability. Thus when deciding which mode of global product development to engage between captive offshore and global partnership, management might want to consider weighing the technological difficulty vs. the coordination difficulty of the product.

In emerging regions, it seems firms are largely driven by the desire to establish presence in those markets hence global outsourcees will likely be developing the least complex products. Most of my interviews indicated that firms expend sizable amounts of resources training their suppliers in emerging markets as a way of securing a footing in the market. Based on the interviews, these suppliers are often turned into partners as firms seek to protect their investments in developing the suppliers’ capability, and secure suppliers against possible hold-up in the future.

However, dynamics in emerging markets are changing as capability is growing as we found from the interviews. This growth in capability is partly driven by investments from
parent firms and partly by rapid industrialization. Additionally, the competition for labor is encouraging firms to develop more interesting products as a way of motivating and retaining talented engineers in emerging markets.

From a strategic importance point of view, I found that firms were likely to develop what they deemed important through captive offshores. The strategic importance was driven by several factors such as competitive product differentiation and perceived future of the industry. I was surprised to find that global outsourcees and global partnerships were developing modules deemed of equal importance to the strategy of the parent firm. Presumably, global partnership would develop modules of more strategic importance. Perhaps today’s global partners can be tomorrow’s competitors; hence firms jealously safeguard modules at the core of their products.

From a regions point of view, I investigated global product development practices in mature as well as emerging markets. Thus my research allows product development leaders to get a sense of what global product development might look like in the future when the emerging markets mature, and as industries head towards the global centers of excellence form of GPD.

2.8 Summary

In this chapter, I investigated the relationship between module complexity, specificity, module strategic importance and designer’s capability, and modes of global product development. My dataset consisted of 118 modules developed in 25 countries outside each program’s headquarters, and I gathered my data over a period of 15 months. Four overarching findings emerged from my work:

Firstly, I found that the most complex modules were likely to be developed through global partnerships, modules of “medium” complexity were more likely to be captive offshored and the least complex modules were likely to be globally outsourced. The differences among the three categories is highest in emerging regions and least (statistically non-existent) in mature regions.
Secondly, relative to captive offshored modules, globally outsourced modules were associated with the highest amount of technological capability. Global partners have "medium" technological capability while captive offshore have the least technological capability. The same relationship holds in mature regions, and in emerging markets captive offshored modules were associated the most technological capability though designer’s technological capability was barely statistically significant.

Thirdly, the most specific modules were more likely to be either captive offshored or developed through global partnerships, and the least specific modules were likely to be globally outsourced. The same relationship holds in mature regions and specificity is not statistically significant in emerging markets.

Finally, strategically important modules were more likely to be captive offshored. However, the difference between the captive offshore mode and the global outsource mode is smaller than that between captive offshore mode and global partnership mode.

2.9 Contributions
I extended the make/buy literature in four key ways:

- I included the global aspect of product development by limiting my study to modules developed outside the program-home country, and considering the development location in my final analysis. This global aspect is increasingly important as many researchers have observed an increase in the practice of global product development.
- I also extended the literature beyond the dichotomous make or buy choices by including the partnerships mode
- I focused my analysis on product development, thus moving beyond manufacturing which had been the staple in the make or buy literature
- I empirically assessed the definition of complexity in global product development because there was no widely used definition of complexity at the module level

These four major contributions create different combinations such as the investigation of the role of complexity on global partnership, global outsourcing and captive offshore as
modes of global product development vs. the make or buy which had been prominent in the literature before.

2.10 Future work
This work can be extended by gathering more data from emerging regions, and running related analysis. I believe the proportion of emerging markets vs. mature markets data (33% vs. 67%) is a representation of the current state of the GPD. However, it appears that more product development is moving to emerging regions; thus creating opportunities for a better understanding of the differences between GPD in mature vs. emerging regions.

Secondly, the role of manufacturing in these modes of GPD was not clear from my interviews and analysis. I could envision the mode of GPD related to module manufacturing as much as I could list examples where that was not the case. Thus this intersection of product development and manufacturing creates research opportunities.

Finally, I investigated four of the several factors involved in making mode decisions in GPD. There are other factors that I reviewed in the literature, which might be important in the global product development of other non-electro-mechanical systems. Once again this line of enquiry creates opportunities for research.
2.11 References


3 Beyond labor cost: complexity and the global product development location advantage

3.1 Introduction
Many leading firms developing complex products globally discuss several benefits associated with the different locations which they have engaged in their Global Product Development (GPD) efforts. For instance, the GE annual report reads “Now spanning the globe, our R&D activities are increasingly concentrated in regions with strong market growth, dynamic innovation and highly qualified people.” (General Electric, 2005; p. 20) The Boeing website reads “The key to this exceptional performance [of the Boeing 787] is a suite of new technologies being developed by Boeing and its international technology development team,” (Boeing, 2007) and the Schneider Electric annual report reads “these centers [product development centers] will play a major role in reducing product expenses” (Schneider Electric, 2005; p. 13). The list of such benefits is long, and I call such advantages location advantages.

However, global product development research is nascent. Thus researchers often generalize from related fields, such as international research and development, and the multinational corporations’ research, in academic discourse about location advantages. I take a slightly different approach and empirically investigate three themes that contribute to an understanding of global product development. I first investigate global product development location advantages using generalized linear models. Such models have not been employed in this stream of research before. Secondly, I investigate the moderating role of product complexity on the location advantages, and lastly I investigate how national capability is related to firm capability in the context of global product development.

3.1.1 Importance of understanding location advantages and complexity
My work has practical importance to senior leadership in product development. Understanding what is driving product development to certain locations with scientific merit, enables the leadership to see through the fog and make informed decisions. Bringing product complexity into the decision processes allows the leadership to better
decide where to send product as influenced by characteristics of the product vs. generic popular understanding of global product development. From experience, firms are making such location decisions on a one-off basis; hence a systematic process might help improve efficiency in global product development. It is my goal in this chapter to shed some light on these dimensions of globally distributed product development.

3.1.2 Structure of this chapter
This chapter is structured such that the next section reviews related literature from the international research and development, and multinational corporations’ research. Section 3.3 discusses my two-phased research protocol. Section 3.4 discusses findings from the qualitative research while Section 3.5 explains how I measured the variables identified from the qualitative portion of the research for quantitative analysis. In Section 3.6, I present my quantitative results, and the remaining sections discuss and summarize work in the chapter.

3.2 Review of the literature
Because global product development literature is embryonic, I will review location benefits as discussed in the multinational corporations, and international research and development streams of research. These streams of research allow me to get a better understanding of each stated benefit of global product development before empirical quantitative investigation.

3.2.1 Labor cost
While corporate America generally claims that global product development is less expensive than local product development, there is a divergence of opinion in academic literature. As reviewed below, some researchers claim that GPD is less expensive; others claim the opposite, while others only posit that there are potential labor cost benefits to global product development. For instance, Eppinger and Chitkara (2006) argue that companies “strive [my emphasis] to reduce product development operating costs by redistributing activities to take advantage of labor arbitrage or to access more affordable capabilities” (p. 24).
Coming from the multinational corporations (MNCs) literature Doz, Santos, and Williamson (2001) argued that firms were drawn to foreign countries by the “access to cheap labor and raw materials” (p. 9). Their findings were grounded in extensive qualitative case studies of thirty six companies from North America, Asia and Europe. When compared to Eppinger et al.’s (2006) study, Doz et al.’s (2001) sample of case studies included companies from the manufacturing sector as well as a significant number of companies from the electronics industry. Dias and Galina (2000), and von Zedtwitz and Gassman (2000) came to the same conclusion as Eppinger et al. (2006) and Doz et al. (2001). Dias & Galina (2000) studied the Brazilian automobile and telecommunications industries, while von Zedtwitz et al.(2000) analyzed location data of over 1000 R&D location sites, and interviewed about 80 R&D managers from a wide range of companies such as BMW, Bayer, Shell and Nokia.

To the contrary, Kumar (2001) found that “the relative cost of qualified R&D personnel, holding supply constant, does seem to affect the global pattern of location of overseas R&D especially for the Japanese [vs. US] MNEs” (p 168). Though the tone of the statement is conciliatory, the statistical analysis did not find a statistically significant labor cost advantage for US multinational corporations. However, Kumar (2001) found a significant cost advantage for the Japanese multinational corporations. The analysis was based on wage data for equally qualified engineers in different countries provided by the Union Bank of Switzerland. Hakanson (1992) also found that inexpensive labor was not an important location advantage for Swedish multinational firms. Coming from an economics tradition, Mansfield, Tecce, & Romeo (1979) studied US companies from the 1970 wave of globalization of development and found that the cost advantage evaporated with the depreciation of the US dollar. Thus Kumar’s (2001) data from the 1990s, Hakanson’s (1992) data from the 1980s and Mansfield et al.’s (1979) data from the 1970s did not find a significant labor cost location advantage in US international research and development.

Proportionally, one would expect a research and development organization to have more employees with advanced degrees than a product development organization. As a result,
one might expect that labor cost might be more varied among product development engineers in different countries than among researchers with doctoral degrees. Thus I will investigate whether labor cost is a statistically significant location advantage in global product development.

3.2.2 Capability
In international research and development, firms have been characterized as exploiting or enhancing their capabilities. In exploiting their capabilities, firms apply capabilities they already have in a foreign market. In enhancing capabilities, firms augment their capabilities using capabilities from their destination region (Belderbos, 2003). The MNC research uses slightly different terms that imply the same ideas of exploitation and exploration. Multinational organizations exploit their capabilities in a foreign country, while international firms enhancing their capabilities (Bartlett & Ghoshal, 1989). Thus it’s not clear from this discussion whether firms predominantly enhance or exploit their capabilities when they internationalize research and development.

However, there is some evidence suggesting that firms largely engage international R&D to enhance their capabilities. For instance, in a study of 32 US, Japanese and European companies, Kuemmerle (1997b) found that firms largely enhanced their capabilities by internationalizing research and development. Likewise, Håkanson & Nobel (1993) found exploitation of foreign R&D resources as a key motivation for international R&D for the 20 largest Swedish firms. Florida (1997) found similar results from a survey of foreign-affiliated R&D labs in the US. Most recently, Ito & Wakasugi (2007) found similar results while studying Japanese firms. Thus firms internationalize research and development to countries with higher national capability.

Findings above address the national capability of the host country. However, national level findings can not always be replicated at the firm level (Cheng & Bolon, 1993). As a result it is prudent to review the role of the firm capability in international research and development, and MNC research. There are two entities of interest at the firm capability level of analysis: the parent firm and the host firm.
In their seminal work, Cohen & Levinthal (1990) argued that capability increases the absorptive capacity of the firm enabling the firm to better exploit host country capability. Thus not only do firms’ internal research and development improve their internally-developed technology; it also makes the firms conversant in new technologies which might not necessarily be developed in-house.

There has been limited systematic empirical analysis of the host (global partner, global supplier to whom development is outsourced or a captive offshore) capability. Zejan (1990) investigated some properties of the host such as size, but did not investigate the host’s capability. Rugman & Verbeke (2001) created an extensive non-empirical framework for characterizing subsidiary capability. Jarillo & Jon (1990) created an empirical framework for characterizing subsidiary strategies but did not address subsidiary capability. I conjecture that the host entity’s capability might play an important role in global product development.

With respect to the specific capability being acquired through internationalization, researchers often agree that distributing research and development efforts provides access to different technological capabilities. The basic argument is that different geographic regions specialize in different types of technology; hence having some form of presence in the regions increases a firm’s access to the technology (De Meyer, 1992; Doz et al., 2001; Westney, 1997). Kogut & Zander (1993) add know-how to this technological capability. They argue that ability to transfer or exploit technological capability is a unique capability in its own right.

In general, the international R&D literature reviewed above is not clear on host national capability, host firm capability or subsidiary capability and the specific capability when discussing the role of capability in international R&D. Product development is different from research. Research and development is “primarily concerned with expanding scientific knowledge and assessing its feasibility” (Leifer & Triscari, 1987; p. 71), while development is focused “on the application of the technology base to operational requirements with the intent of bringing a new (or modified) product into existence”
The two are linked by a technology transfer process (Eldred & McGrath, 1997). Thus, I will investigate how both national capability and firm capability are related in global product development.

### 3.2.3 Market

As found by Hakanson (1992) and Zejan (1990) using a survey of the top 20 Swedish firms, large market size attract more research and development. This was further supported by von Zedtwitz et al. (2000) using a broader data set, and Mansfield et al. (1979) found that a firm’s R&D expenditure abroad varied directly with a firm’s sales derived from abroad.

However, Zejan (1990) and Odagiri & Yasuda (1996) also found that the more a firm exports, the more foreign research the company does. Papanastassiou & Pearce (1991) found that the higher the production share to the local (from the parent firm point of view) market, the lower the amount of foreign R&D that firm performed. These secondary effects would seem to indicate that the larger the local market relative to the export market, the less the amount of research and development done in that country.

Research and development is more removed from the final consumer than product development; hence I expect the market size to play a key role in increasing the amount of product development in my research. Thus, I will investigate the effect of market size and market growth rate on the amount of product development done in the particular country.

### 3.2.4 Large labor pool

Chief among the international resources that companies get through global product development is labor. Studying Japanese firms and using the number of researchers per million as a measure of the available labor pool, Ito & Wakasugi (2007) found that firms were attracted to regions with large pools of labor. Kumar (2001) found similar results in his study of Japanese and American firms, and Hemmert (2004) found that R&D personnel were a critical factor in enabling foreign technology acquisition by German and Japanese firms.
Other researchers have argued that it’s not the quantity but the quality that matters (Farrell et al., 2005). In this research, the quality of the engineers is closely tied to the capability; hence I will investigate how the sheer number of engineers influences location in global product development.

3.2.5 Political and other benefits

Researchers have also argued that locating product development in the country in which products are sold boosts the company’s public relations profile and entitles the company to local tax benefits. Odagiri and Yasuda’s (1996) study is noteworthy given Toyota’s position in the United States. In their study, Odagiri et al. (1996) compared the ratio of exports (from Japan) to a foreign country and total sales in that country, and found that Japanese firms tended to have higher research and development expenditure in countries where the ratio was high. They interpreted this to mean that Japanese companies often try to develop products in a country where the goods are sold as a way of avoiding political back-lash.

However, one might argue that the same finding supports the conjecture that Japanese sense their markets better through developing products in those markets (Doz et al., 2001). Thus companies benefit by being located near the lead users who can influence trends around the world (von Hippel, 1988).

3.2.6 Literature summary and opportunities for contribution

In summary, market size, capability, labor pool, labor cost, and political benefits are factors important for research and development leaders to consider as location advantages. Whether these factors apply to product development as well is not clear. As mentioned earlier, product development tends to be closer to the customer, requires more coordination than research and development, and more often than not, ends in a physical product. Given these differences, I intend to first investigate whether these factors identified as important in international research and development are important in global product development as well. Secondly, I will go beyond and investigate the relationship
between product complexity and the location drivers in global product development. Finally, I will examine the relationship between national capability and firm capability.

3.3 Research protocol
My research protocol consists of two major phases. The first phase is largely exploratory and qualitative while the second phase is quantitative. The qualitative methods allowed me to “capture a more complete, holistic, and contextual portrayal of the units under study” (Jick, 1979; p. 603), while the second phase focused on the quantitative methods as a way to systematically analyze statements, hunches, anecdotes and quotes from the qualitative findings.

3.3.1 Phase I: Exploratory research
According to Eisenhardt (1989) and Stebbins (2001) exploratory research yields empirically valid hypotheses. Thus my goal in this phase is to empirically and systematically discover the critical factors that influence decisions on where to develop product modules. I started the process guided by the reviewed literature, collected some data in the field, refined my hypotheses and repeated the process until I had a stable set of hypotheses.

3.3.1.1 Phase I case selection process
The population consisted of product development leaders who had worked or were working in globally distributed product development projects of complex electromechanical systems. Thus the population included leaders working on medical equipment such as magnetic resonance imaging machines, industrial equipment such as earth moving equipment, electronic equipment such as large computer servers etc. From that population, I used quota sampling and interviewed product development leaders working at large American companies with the goal of increasing the diversity of opinions in the sample. In order to avoid generalized superfluous discussions, my interviews were centered on modules developed outside the program home-country and the processes involved.

The first case study was company A (a large Fortune 10 American company), where I spent 500 hours as a global product development engineer on a clean-energy, high-tech
globally distributed product development project that involved four companies in three countries across Europe and North America. In the spirit of quota sampling, I then broadened my cases to chief technology officers, directors and vice presidents of engineering at 17 other companies involved in the development of electro-mechanical systems. These 17 were chosen to test the replicability of findings from the initial case study.

By focusing on large American companies, I controlled for possible firm size and national culture influencing the location choices. While there is no consensus on whether firm size proportionally increases the amount of R&D conducted by the firm (Cohen & Klepper, 1996), one can think of examples where large firms proportionally develop more products globally than smaller firms. On national culture (and associated geography and institutions) European firms tend to be most globally distributed, followed by American firms while Japanese firms are least globally distributed in product development. Additionally researchers have occasionally found differing results when comparing Japanese and American companies (e.g. Kumar’s (2001) findings on the effect of cost in the distribution of research and development. Thus it is important to control for firm size and national origin of the parent firm.

3.3.1.2 Phase I data collection process
The data collection process began with open-ended interviews on factors that drive product development to different countries. Each interview was done and recorded in person, and lasted from 30 minutes to 3 hours depending on the seniority of the interviewee and stage in the research process. The average interview lasted for an hour. The interviews tended to be longer during the early phases of the research and as the responses converged, I used semi-structured interviews which tended to be shorter. The interview data was supplemented by observation data as I worked on a globally distributed product development project for 500 hours.

Most of the product development leaders were located in the US and a few were located in Europe and Asia though they all worked for American companies. All in all I conducted 80 interviews from 18 different large American companies over a period of 15
months including the initial 500 hours spent in the field as a global product development engineer.

3.3.2 Phase II: Multiple embedded case studies
My over-arching goal during this second phase was to obtain quantitative data for statistical analyses with the goal of explaining location decisions made in global product development. Drivers of interest were first gathered from the literature, and sieved using exploratory research in Phase I. This enabled the research to be specific to global product development instead of international research and development.

3.3.2.1 Phase II: Case selection process
There were two populations during this phase of the research: the country and the module populations. Similar to Pisano (1990), the country population consisted of the top 50 countries that trade with the US in electro-mechanical systems. The modules population consisted of tier one electro-mechanical modules developed by (or for) large American firms outside the program home-country. Once again, I used quota sampling strategy for the modules. Beyond the first case study, I limited each company to at most 12 modules.

3.3.2.2 Phase II: Data collection processes
Because I used two populations for my model, I will describe how I obtained data from each of the populations.

3.3.2.2.1 Country-level data collection process
We collected the list of countries for the study from the United Nations Commodity Trade Database (UNComtrade, 2008). Using the Harmonized System 2002 codes 85 and 87, I chose the top 50 (by value) countries that export modules of electro-mechanical systems to the US.

With the list of countries in hand, I gathered characteristics of each country using several databases available through subscription. Though I used the best data available to any researcher, there are weaknesses associated with using databases not specifically constructed for a research project at hand. In my case, definitions varied slightly across countries. For example, the definition of an engineer in India includes an IT specialist while it does not in the US. These differences extend into the US as well. For instance,
computer science is in the engineering department at MIT, but in the science department at Duke University. Is a computer science graduate an engineer or a scientist?

In addition to these slightly different definitions, some data is politically sensitive hence countries might report misleading numbers (Wadhwa et al., 2007). Countries are also subject to different levels of constraints e.g. the amount of red tape associated with getting the data, and different areas of constraints e.g. financing vs. red tape in getting the data. To mitigate these weaknesses, I triangulated three data sources for each data point.

3.3.2.2 Module-level data collection process
The module data collection process was partially combined with qualitative data gathering described above. After establishing contact at the company, I set up a phone or in person conversation with the product development leader. At the beginning of each interaction, I described the two phases of the research. I then spent most of the time having qualitative discussion about global product development as described above, and reserved some time at the end where I explained the data that I needed to measure the module complexity.

Once they understood the data requirements, I gave the respondents a week to fill out the rest of the data template. In addition to the template, I gave them a document (see Appendix A) which explained each column of data to serve as a reference. Most respondents returned the data template within a couple of days. All in all, I had 156 modules developed in 25 countries from 18 companies. For more details on how I collected module level data, please see chapter two.
3.4 Exploratory research findings: Hypotheses

In this section I am going to present findings from the exploratory phase of the research. Table 3.1 lists the companies in the study. There are three major groups of companies: industrial, medical device and electronics companies. From the location advantage point of view, there were no differences in findings.

Table 3.1: List of companies in the study

Table 3.2 below lists ranks of the interviewees from the 18 companies in Table 3.1. In order to capture both technical and business constructs, I interviewed across the entire product development organization from engineers to the heads of product development.

Table 3.2: Interviewees and their ranks

<table>
<thead>
<tr>
<th>Interviewee rank</th>
<th>Number of interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Vice Presidents / Chief Technology Officers</td>
<td>3</td>
</tr>
<tr>
<td>Vice Presidents</td>
<td>3</td>
</tr>
<tr>
<td>Directors</td>
<td>19</td>
</tr>
<tr>
<td>Chief Engineers / General Managers</td>
<td>5</td>
</tr>
<tr>
<td>Managers</td>
<td>11</td>
</tr>
<tr>
<td>Supervisors</td>
<td>14</td>
</tr>
<tr>
<td>Engineers</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
</tr>
</tbody>
</table>

The interviewees were asked for factors they considered (or that were considered) when the company/program made the decision to locate product development in specific countries. Representative quotes are described below and the frequency of each factor is shown in Figure 3.1.

3.4.1 National capability

I define national capability as the comparative expertise in a country to develop a given class of related products. For instance, the Germans are well known for their prowess in developing mechanical systems, hence their national capability in mechanical systems is high. In analyzing the qualitative interviews, I coded as "national capability" ideas that referenced the capability of a country or the region within a country. For instance, the statement from one of the group vice presidents: “There are ecosystems that have been
created that we tend to work with in the early stages. At the very beginning, we take advantage of the ecosystem. When it [product] matures we move it to low cost regions” was coded as referencing the importance of national capability and cost. The statement “we really look for expertise around the world, and we are also investigating these emerging markets: Mexico, Vietnam and Eastern Europe” was coded as national capability and markets.

3.4.2 Market
The market is the total value of goods consumed in a particular country. The statements: “we are growing capability in Guangzhou for escalators because they will be an important market” and “we keep engineers in these areas to make sure that we meet our customer’s requirements in those areas” were coded as markets. While the former speaks to the size of the market, the later speaks to the ability to sense a market better.

3.4.3 Cost
There are several costs involved in product development. The cost of labor is often sited as one of the benefits associated with moving product development abroad, hence by cost I specifically refer to the cost of engineers in product development. The cost of capital equipment is not included in this metric since it depends on the infrastructure of the country in question. For instance, some firms building extensive plants in China have to build the infrastructure leading to those plants as well. Statements such as: “we save money through the global partnerships, each company puts in something” and “we look around for skill set and cost” were coded as referencing cost.

3.4.4 Labor pool
The labor pool is the number of engineers available in the country. Statements such as “we go to India because they have a talented workforce. Because of our name, we are able to attract the best engineers” and “our workforce in India is youthful” were coded as labor pool.

3.4.5 Other variables
There were some other variables that I did not investigate further because there wasn’t enough data for triangulations. These include capacity, intellectual property protection, and the belief that there were no reasons for globalizing product development.
Armed with these findings and the literature, I derived hypotheses listed below. The directionality of each hypothesis is influenced by observations in the field and the directionality implied in the literature review above.

H1: As the average national capability increases, the likelihood of product development in that particular country increases.

H2: As market size increases, the likelihood of product development in that particular country increases.

H3: As market growth rate increases, the likelihood of product development in that particular country increases.

H4: As the labor cost decreases, the likelihood of product development in that particular country increases.
H5: As the number of engineering graduates increases, the likelihood of product development in that country increases.

H6: There is significant tendency to develop complex modules in countries with higher national capability.

H7: National capability is directly associated with firm capability.

3.5 Negative binomial model data description

This section describes how the variables above were quantitatively measured. The model is shown in Equation 3-1 below. For more technical details about the model, please see Appendix B.

Equation 3-1: Model of location advantages in global product development

\[
\text{# of modules} = \beta_1 (\text{National Capability}) + \beta_2 (\text{Mkt Size}) + \beta_3 (\text{Mkt Growth}) + \beta_4 (\text{# of Eng. Grads.}) \\
+ \beta_5 (\text{Labor Cost})
\]

3.5.1 Timing

From the qualitative interviews, one director of global sourcing commented “We try to look out five years, and get a sense of where the advantage lies in 5 years.” Another commented that the development of their systems takes 4 years. Given the mix of complex products in the study, it is fair to assume that the earliest decisions were made about five years ago, and the most recent decisions were made within the last couple of years. As a result, independent variable values discussed in this work are an average of values from 2003, 2004 and 2005. For instance, each market size data point reported in this dissertation is an average of three market size (GDP) values corresponding to the years 2003, 2004 and 2005.

3.5.2 Dependent variable

The unit of analysis in the model is the country, and the dependent variable is the number of modules (from chapter two) developed in each country. The list of countries consists of the top 50 countries by export value of electro-mechanical systems to the US. That is, the list of countries consists of the top 50 countries from which the US imports modules.
classified using the Harmonized System 2002 under code 85 and 87 as captured by the UNcomtrade (2008).

### 3.5.3 Independent variables

As mentioned in the data collection phase, the independent variables data comes from databases available through subscription. In order to circumvent some challenges associated with using data created for other purposes, I triangulated each data point with values from three different sources. Table 3.3 summarizes these databases for each independent variable. Details about each independent variable are discussed in the subsequent subsections.
Table 3.3: Databases used in triangulating independent variables

<table>
<thead>
<tr>
<th>Sources of Data for Triangulation</th>
<th>Data used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market Size and Growth Rate</strong></td>
<td></td>
</tr>
<tr>
<td>– World Bank (WB)</td>
<td>Correlations &gt;0.90</td>
</tr>
<tr>
<td>– International Monetary Fund (IMF)</td>
<td>Used IMF data</td>
</tr>
<tr>
<td>– United Nations Conference on Trade and Development (UNCTAD)</td>
<td>( r^2 = 1 ), randomly chosen</td>
</tr>
</tbody>
</table>

*Exchange rates*

<table>
<thead>
<tr>
<th>Exchange rates</th>
<th>Data used</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Federal Reserve Bank</td>
<td>correlations &gt;0.90</td>
</tr>
<tr>
<td>– International Monetary Fund</td>
<td>Used IMF data as well</td>
</tr>
<tr>
<td>– World Bank</td>
<td></td>
</tr>
</tbody>
</table>

*Number of engineering graduates*

<table>
<thead>
<tr>
<th>Number of engineering graduates</th>
<th>Data used</th>
</tr>
</thead>
<tbody>
<tr>
<td>– National Science Foundation (NSF)</td>
<td>Correlations &gt;0.90</td>
</tr>
<tr>
<td>– United Nations Educational, Scientific and Cultural Organization (UNESCO)</td>
<td>Used NSF data</td>
</tr>
<tr>
<td>– Organization for Economic Cooperation and Development (OECD)</td>
<td>(most specific, larger N)</td>
</tr>
</tbody>
</table>

*Labor cost*

<table>
<thead>
<tr>
<th>Labor cost</th>
<th>Data used</th>
</tr>
</thead>
<tbody>
<tr>
<td>– International Labor Organization (ILO)</td>
<td>Correlations &gt;0.90</td>
</tr>
<tr>
<td>– Bureau of Labor Statistics (BLS)</td>
<td>Used ILO manufacturing data</td>
</tr>
<tr>
<td>– Organization for Economic Cooperation and Development (OECD)</td>
<td>(larger N, 0.93 correlation with engineering)</td>
</tr>
</tbody>
</table>

*National capability*

<table>
<thead>
<tr>
<th>National capability</th>
<th>Data used</th>
</tr>
</thead>
<tbody>
<tr>
<td>– United Nations Commodity and Trade Statistics</td>
<td></td>
</tr>
<tr>
<td>– World Competitiveness Report</td>
<td>Used both</td>
</tr>
</tbody>
</table>
3.5.3.1 Market size and growth rate

I used the Gross Domestic Product (GDP) at the reference year current prices in US dollars as a surrogate for national market. The GDP values are based on expenditure, and converted into US dollars using exchange rates provided by country economists to a central inter-governmental body such as the International Monetary Fund (IMF, 2008). Though the GDP can be measured from the production side as well, I am interested in what is consumed in the country.

Because of the standard nature of GDP, the World Bank (World Bank Group, 2008) and the United Nations Conference on Trade and Development (UNCTAD, 2007) use the same definitions and measures for GDP. The triangulation of the three different data sources is shown in Table 3.4. Since the three sources are statistically identical (actual values are slightly different), I randomly chose to use the IMF data for market size in the location advantage model. I also used the same IMF data sources for the market growth rate of each country.
Table 3.4: Correlations among IMF, WB and UNCTAD as sources of market size

<table>
<thead>
<tr>
<th>Correlations Among WB, IMF and UNCTAD Values as Sources of Market Size</th>
<th>UNCTAD</th>
<th>WB</th>
<th>IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Nations Conference on Trade and Development (UNCTAD)</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>1.00**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>World Bank (WB)</td>
<td>Pearson Correlation</td>
<td>1.00**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>International Monetary Fund (IMF)</td>
<td>Pearson Correlation</td>
<td>1.00**</td>
<td>1.00**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
3.5.3.2 Number of engineers

Gereffi et al. (2008) site several definitions of an engineer: “an individual working in an engineering occupation, an individual whose most recent degree is in a traditional engineering discipline, or an individual working in a position that requires specific engineering knowledge (p. 14). I will define an engineer as an individual whose first degree is in engineering as defined by the appropriate local authorities.

The first data set for the number of engineering graduates is from the National Science Foundation (NSF). The National Science Foundation (National Science Board, 2008) publishes the most specific number of first university degrees awarded in engineering by several countries. These numbers are captured in their biennial Science and Engineering Indicators Report, of which the latest was published in 2008. Since I am interested in values from the 2003, 2004 and 2005 time frame, I can only use their published numbers for 2004. As a biennial report published every even year, they did not publish values for the years 2003 and 2005.

The second source of data was the Organization for Economic Co-operation and Development which provides data on engineering and engineering trades (ISC 52) graduates from its member countries and a few selected countries (OECD, 2008). Graduates are defined as those who complete their degrees in the reference year. The data is reported by national ministries of education or national statistics office. Reported values in this study are an average of values from 2003, 2004 and 2005.

Finally, the United Nations Educational Scientific and Cultural Organization (UNESCO, 2008) collects data on graduates through its annual UNESCO Institute of Statistics (UIS) survey to national authorities. The UNESCO categorization of fields of study is fairly broad and the closest category to engineering is their “graduation in engineering, manufacturing and construction” category. Similarly, I used the average number of graduates from 2003, 2004 and 2005 for my analysis, and the correlations among the three data sources are shown in Table 3.5 below.
<table>
<thead>
<tr>
<th></th>
<th>NSF</th>
<th>OECD</th>
<th>UNESCO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>National Science Foundation</strong></td>
<td>Pearson Correlation</td>
<td>1</td>
<td>.92**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>42</td>
<td>27</td>
</tr>
<tr>
<td><strong>Organization for Economic Co-operation and Development</strong></td>
<td>Pearson Correlation</td>
<td>.92**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td><strong>United Nations Educational Scientific and Cultural Organization</strong></td>
<td>Pearson Correlation</td>
<td>.94**</td>
<td>.97**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>37</td>
<td>27</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
3.5.3.3 Labor cost
The International Labor Organization (ILO, 2007) compiles labor statistics from a wide breadth of countries. I used employees’ average earnings as the labor cost from the parent company point of view: “The data on average earnings, generally taken from establishment payrolls, usually cover cash payments received from employers (before deduction of taxes and social security contributions payable by workers), such as remuneration for normal working hours, overtime pay, incentive pay, earnings of piece-workers; remuneration for time not worked (annual vacation, public holidays, sick leave and other paid leave); bonuses and gratuities. In a few cases, average earnings are compiled on the basis of social insurance records; social insurance statistics usually yield lower averages than payroll data because overtime payments, incentive pay, etc., may be excluded, as well as wages exceeding a certain upper limit” (ILO, 2008).

In engineering, the ILO published data on petroleum and natural gas engineering (code 14), chemical engineering (code 52) and power distribution and transmission engineering (electrical engineering) (code 76). The data is published in local currency hence I converted the values into US dollars using representative rates from the International Monitory Fund (IMF, 2008). Where IMF data was not available, I used exchange rates from the World Bank (World Bank Group, 2008). Correlations among these three types of engineering and the average of all three are shown in Table 3.6 below. Because of the high correlations, and large number of countries covered, I used the average engineering labor cost for the forthcoming analysis.

In order to triangulate trends observed in the engineering labor cost data, I analyzed trends in manufacturing wages since other sources of engineering wages were scant. The Bureau of Labor Statistics (BLS) (Bureau of Labor Statistics, 2008b) provides manufacturing labor cost across a variety of countries that most heavily trade with the US. The ILO’s “average earnings” is equivalent to the BLS’ “direct pay” which the BLS defines as a sum of “basic wages, piece rate, overtime premiums, Shift differentials, bonuses and premiums paid regularly, cost-of-living adjustments, pay for time not
worked (vacations, holidays, and other leave, except sick leave), seasonal and irregular
bonuses, Social allowances, and pay in kind” (Bureau of Labor Statistics, 2008a).

Table 3.7 shows the correlations among the three labor cost surrogates. Since the
correlation between the manufacturing and engineering wages is 0.93, and the
manufacturing data set has a larger N i.e. 38 vs. 21, I will use the ILO manufacturing
wages as a surrogate for engineering labor cost in the rest of this study.
### Table 3.6: Correlations among engineering wages from the ILO

<table>
<thead>
<tr>
<th>Correlations Among Different Engineering Wages from the ILO</th>
<th>Chemical Engineering</th>
<th>Electrical Engineering</th>
<th>Petroleum and Gas Engineering</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Engineering</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>.99**</td>
<td>.97**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>20</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>Pearson Correlation</td>
<td>.99**</td>
<td>1</td>
<td>.94**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>17</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Petroleum and Gas Engineering</td>
<td>Pearson Correlation</td>
<td>.97**</td>
<td>.94**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>12</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Average</td>
<td>Pearson Correlation</td>
<td>1.00**</td>
<td>.99**</td>
<td>.98**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>20</td>
<td>17</td>
<td>14</td>
</tr>
</tbody>
</table>

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

### Table 3.7: Correlations among manufacturing and engineering wages from ILO and BLS

<table>
<thead>
<tr>
<th>Correlations between the ILO and BLS as Sources of Engineering Wages</th>
<th>ILO Manufacturing</th>
<th>BLS Manufacturing</th>
<th>ILO Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILO Manufacturing</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>.89**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>BLS Manufacturing</td>
<td>Pearson Correlation</td>
<td>.89**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>ILO Engineering</td>
<td>Pearson Correlation</td>
<td>.93**</td>
<td>.88**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

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

The national capability of each country is calculated using Equation 3-2 below.

**Equation 3-2: Calculation of the national capability**

\[
\text{National Capability}(c,i) = \left( \frac{\sum_{i} x(c,i)}{\sum_{i} \sum_{c} x(c,i)} \right) \times \text{(value chain presence)}
\]

Where:

- **National Capability** \((c,i)\) – national capability of country \(c\) in developing product \(i\)
- \(x(c,i)\) = exports of country \(c\) in product \(i\), to the entire world, thus term in squared brackets is the revealed comparative advantage of country \(c\) in product \(i\)
- **Value Chain Presence** – the response to “exporting companies in your country are (1=primarily involved in resource extraction or production, 7=not only produce but also perform product design, marketing sales, logistics, and after sales services)” in the Global Competitiveness Report

In a nutshell, the national capability is a product of the revealed comparative advantage (RCA) (Balassa, 1986; Hidalgo *et al.*, 2007) and the value chain presence (Lopez-Claros *et al.*, 2005; Porter *et al.*, 2003, 2004) of products exported from that country. The numerator in the revealed comparative advantage is a ratio of what a country exports in product \(i\), to its total exports. The denominator is the ratio of world trade in product \(i\) to total world trade. Thus the revealed comparative advantage gives us a relative sense of how good a country is in producing and exporting product \(i\).

However, some countries simply manufactured products without necessarily developing the products. To get the product development aspect of the RCA, I multiplied the RCA
by the response to the value chain presence question in the *Global Competitiveness Report* which addresses whether companies in a country are involved in product development or simply manufacturing.

### 3.6 Negative binomial model results

Because the dependent variable is not continuous and not normally distributed, I used a generalized linear model to test hypotheses on location advantage (Garson, 2008a).

#### 3.6.1 Model specification

Figure 3.2 is a frequency chart of the number of modules developed in a given country. For instance, 17 modules were developed in 1 of the 45 countries, while 5 modules were developed in two of the 45 countries etc. From the initial list of 50 countries, I dropped all countries that were missing at least two data points from the analysis. From Figure 3.2, it is apparent that the dependent variable in not normally distributed. Based on the deviance results from Table 3.8 the dependent variable most closely follows a negative binomial distribution. For more details on the negative binomial distribution, please see Appendix B.

*Figure 3.2: Plot of the dependent variable distribution*
Table 3.8: Deviance of dependent variable distribution

<table>
<thead>
<tr>
<th>Distribution Function</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>14.47</td>
</tr>
<tr>
<td>Poisson</td>
<td>37.84</td>
</tr>
<tr>
<td>Negative Binomial</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Because of heteroskedasticity (see Appendix B) in the independent variables I specified the link function as a negative binomial distribution as well. Because the distribution is used when the variance is larger than the mean, the specification of the distribution includes a dispersion parameter, k, (see Equation 3.3) which reduces heteroskedasticity in the independent variable.

Equation 3.3: One form of the specification of the negative binomial distribution

$Negative \text{ Binomial}(x) = \log \left( \frac{x}{x + k - 1} \right)$

3.6.2 Pooling captive offshore, global outsource and global partnership modules together

Our modules data consists of modules which were either captive offshored, globally outsourced or developed through global partnerships. It is plausible that firms might put more thought into captive offshoring or global partnerships compared to global outsourcing arrangements. As a result I tested the difference of means for each independent variable ($\text{Mean}(\chi)$) across countries where they predominantly employed global partnership, captive offshores, global outsource or where they did not do any product development. The predominance of a mode is measured by the majority of the three modes in that particular country, and I removed countries where there was no dominant mode of global product development for this portion of the analysis.

$H_0$: $\text{Mean}(\chi)_{\text{global-partnership}} = \text{Mean}(\chi)_{\text{captive-offshore}} = \text{Mean}(\chi)_{\text{global-outsource}} = \text{Mean}(\chi)_{\text{no-development}}$

$H_A$: $\text{Mean}(\chi)_{\text{global-partnership}} \neq \text{Mean}(\chi)_{\text{captive-offshore}} \neq \text{Mean}(\chi)_{\text{global-outsource}} \neq \text{Mean}(\chi)_{\text{no-development}}$
Because of the heteroskedasticity in the independent variables, I used the Brown-Forsythe robust test of the equality of means (see Appendix B). Results for the hypotheses tests are shown Table 3.9 below.

Table 3.9: Tests of mean equality across modes of global product development

<table>
<thead>
<tr>
<th>Robust Tests of Equality of Means</th>
<th>Statistic</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Engineers</td>
<td>2.04</td>
<td>3</td>
<td>14.11</td>
<td>0.15</td>
</tr>
<tr>
<td>National capability</td>
<td>1.26</td>
<td>3</td>
<td>12.08</td>
<td>0.33</td>
</tr>
<tr>
<td>Market Growth Rate</td>
<td>0.42</td>
<td>3</td>
<td>16.73</td>
<td>0.74</td>
</tr>
<tr>
<td>Market Size</td>
<td>1.32</td>
<td>3</td>
<td>6.96</td>
<td>0.34</td>
</tr>
<tr>
<td>Engineering Wages</td>
<td>1.61</td>
<td>3</td>
<td>26.83</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Given the results in Table 3.9, I can not reject the null hypothesis for all the independent variables; hence I pooled all modules for the rest of this analysis.

3.6.3 Location advantage hypotheses tests results

Table 3.10 below summarizes the hypotheses tests results. Model 1 includes all variables corresponding to my hypotheses i.e. national capability, market size, market growth rate, labor cost and number of engineering graduates. Because of the high correlation between the number of engineering graduates and the market growth rate (see Table 3.11) I dropped the market growth rate from the analysis. The market growth was the non-significant of the two, and it did not emerge as a key location factor from my qualitative interviews. Thus the data does not support hypotheses three (H3) that the number of modules developed in a country does increase with an increase in the market growth rate.

Model 2 is the best specified model. The coefficients support the hypotheses that ceteris paribus, as each of national capability, market size, and number of engineering graduates increase, the likelihood of product development in that country increases. In other words, the data supports hypotheses H1, H2 and H5. However, hypothesis H4 i.e. as labor cost decreases, the likelihood of product development increases, is not supported by the data.

Model 3 tests the robustness the results. From the 118 modules in the analysis, I dropped 40 modules from company A because the company was overrepresented in the data set.
The overrepresentation was driven by the first 3 months of the 15-month data collection process which I spent as a global product development engineer at the company. As the model 3 shows, results are robust to removing company A from the study.

As described above (see Section 3.5.1), each independent variable is an average of three values from 2003, 2004 and 2005. However, I also tested the robustness of the results to time. I ran the same analysis with just the data from 2005. As shown model 4 in Table 3.10, the results were statistically the same; hence my findings are robust to specific time within my stated time period.
Table 3.10: Location advantage hypotheses tests results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimated Coefficients</th>
<th>Model 1 (all data)</th>
<th>Model 2 (all data)</th>
<th>Model 3 (Without Co. A)</th>
<th>Model 4 (2005 only)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>β1</td>
<td>β2</td>
<td>β3</td>
<td>β4</td>
</tr>
<tr>
<td>Market Size</td>
<td></td>
<td>2.75E-05***</td>
<td>2.50E-05***</td>
<td>3.99E-05***</td>
<td>2.78E-05***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9.45)</td>
<td>(9.18)</td>
<td>(13.02)</td>
<td>(9.43)</td>
</tr>
<tr>
<td>National Capability</td>
<td></td>
<td>1.70E-02</td>
<td>3.00E-02***</td>
<td>3.7E-02**</td>
<td>3.10E-02***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.66)</td>
<td>(9.56)</td>
<td>(3.88)</td>
<td>(10.30)</td>
</tr>
<tr>
<td>Number of Engineers</td>
<td></td>
<td>2.11E-06***</td>
<td>1.26E-06***</td>
<td>1.57E-06***</td>
<td>1.32E-06***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7.56)</td>
<td>(11.50)</td>
<td>(10.03)</td>
<td>(10.42)</td>
</tr>
<tr>
<td>Labor Cost</td>
<td></td>
<td>3.28E-06</td>
<td>5.26E-05</td>
<td>3.47E-05</td>
<td>5.57E-05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.00)</td>
<td>(0.95)</td>
<td>(0.21)</td>
<td>(1.02)</td>
</tr>
<tr>
<td>Market Growth Rate</td>
<td></td>
<td>-6.70E-02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.96)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model likelihood Chi-Square Significance</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>28.06</td>
<td>26.28</td>
<td>23.3</td>
<td>25.43</td>
<td></td>
</tr>
<tr>
<td>Number of countries with development</td>
<td>25 of 40</td>
<td>25 of 40</td>
<td>24 of 40</td>
<td>22 of 40</td>
<td></td>
</tr>
<tr>
<td>Number of modules</td>
<td>118</td>
<td>118</td>
<td>88</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.1  **p < 0.05  ***p<0.01
Table 3.11: Model 1 Parameters correlation matrix

<table>
<thead>
<tr>
<th>Model 1 Correlations of Parameter Estimates</th>
<th>(Intercept)</th>
<th>Market Size</th>
<th>National Capability</th>
<th>Number of Engineers</th>
<th>Labor Cost</th>
<th>Market Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Size</td>
<td>0.14</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Capability</td>
<td>-0.62</td>
<td>-0.06</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Engineers</td>
<td>0.44</td>
<td>0.31</td>
<td>-0.59</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor Cost</td>
<td>-0.75</td>
<td>-0.35</td>
<td>0.02</td>
<td>-0.11</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Market Growth Rate</td>
<td>-0.80</td>
<td>-0.32</td>
<td>0.65</td>
<td>-0.87</td>
<td>0.49</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 3.12: Model 2 Parameters correlation matrix

<table>
<thead>
<tr>
<th>Model 2 Correlations of Parameter Estimates</th>
<th>(Intercept)</th>
<th>Market Size</th>
<th>Number of Engineers</th>
<th>Labor Cost</th>
<th>National Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Size</td>
<td>-0.25</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Engineers</td>
<td>-0.88</td>
<td>0.09</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor Cost</td>
<td>-0.68</td>
<td>-0.22</td>
<td>0.75</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>National Capability</td>
<td>-0.27</td>
<td>0.23</td>
<td>0.00</td>
<td>-0.42</td>
<td>1.00</td>
</tr>
</tbody>
</table>
3.6.4 Complexity moderating effect hypothesis

To test the moderating effect of complexity on the factors driving product development to specific locations, I used the Brown-Forsythe robust test of the equality of means across each value of each independent variable. In other words, I tested whether the corresponding average module complexity increases as the independent variable increases. For example, I tested whether the average module complexity increased as the market size increased.

H₀: Average module complexity is the same across all values of the independent variable
H₁: Average module complexity is not the same across all values of the independent variable

From the significance values from Table 3.13, I reject the null hypothesis for national capability, but cannot reject the null hypotheses for all other independent variables. Thus the seventh hypothesis (H7) is statistically supported by the data: there is a statistically significant tendency to develop more complex modules in countries with higher national capability.

Table 3.13: Robust complexity test equality of means

<table>
<thead>
<tr>
<th></th>
<th>N (modules)</th>
<th>Statistic</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>111</td>
<td>1.59</td>
<td>17</td>
<td>30.55</td>
<td>0.13</td>
</tr>
<tr>
<td>National capability</td>
<td>98</td>
<td>2.94</td>
<td>20</td>
<td>23.25</td>
<td>0.01</td>
</tr>
<tr>
<td>Number of Engineers</td>
<td>111</td>
<td>1.59</td>
<td>17</td>
<td>30.55</td>
<td>0.13</td>
</tr>
<tr>
<td>Labor Cost</td>
<td>109</td>
<td>1.56</td>
<td>16</td>
<td>30.17</td>
<td>0.14</td>
</tr>
</tbody>
</table>

a. Asymptotically F distributed.
b. Number of modules is less than 118 because I dropped countries that developed only one module from the analysis. I also dropped countries that were missing any values

3.6.5 National capability vs. firm capability

As discussed in Section 3.4.1, national capability is measured as the product of the national revealed comparative advantage and the value chain presence. Firm capability is measured using an above averaged, average and below average score as discussed in Section 2.5.3. Since the unity of analysis is the country, I compared the national capability to the average firm capability in that nation.
To test the relationship between national capability and firm capability, I divided each variable into two at its mean, and tested independence between the two independent variables using the Pearson’s Chi-square test (see Appendix B). The observed values are shown in Table 3.14.

Table 3.14: Chi-Squared Test of Independence

<table>
<thead>
<tr>
<th>National Capability</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm Capability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

H₀: There is an association between national capability and firm capability
Hₐ: There is no association between national capability and firm capability

The chi-squared test yields Pearson Chi-square value of 1.51, which is equivalent to a significance of 0.22. Thus I can not reject H₀, and I conclude that there is an association between national capability and firm capability. Thus more capable firms are more likely to be located in countries with high national capability. For example, specific firms particularly good at designing mechanical systems are more likely to be located in countries such as Germany with high national capability in designing mechanical systems than Finland whose national capability is higher in electronic systems.

3.7 Discussion and implications

In this chapter, I found that firms were drawn to locations with high market size, large pools of engineers and high national capability. From the standardized coefficients, the market size was the most important location advantage. This finding supports my conjecture that global product development is closer to the end user than research and development; hence the market would play a critical role. However, it was surprising to find that the market growth rate was not statistically significant as a location advantage. The product of market size and market growth rate was highly correlated with the market size, hence I statistically could not differentiate between the two i.e. market size, and the
product of market size and market growth rate. However, findings from qualitative interviews indicated that the market size was the key location advantage.

The number of engineers was the second most important location advantage, while the national capability was the third most important location advantage from my data. In the light of findings from the qualitative portion of the research that firms do build capability if they deemed a region important, these statistical findings are in line with my understanding.

I also found that labor cost was not a statistically significant location advantage in the context of global product development. Based on the qualitative interviews, the insignificance of labor cost might be explained by the increase in labor costs as driven by inflation differentials, and increased competition for skilled among firms in a particular region.

In the case of China and India, the two countries are producing a significant number of engineers, but those engineers are not as qualified as the engineers produced in the US according to Wadhwa et al. (2007). Farrell et al. (2005) of the McKinsey Global Institute found that only 13% of the engineers from China and India would be suitable to do the high level engineering work in the US. However, they did not discuss the fraction of engineering graduates in the US who are capable of doing high level engineering work. Thus competition for the top engineers is stiff. According to the qualitative interviews, firms end up paying more and providing more interesting work instead of mundane product development tasks, in order to keep the most qualified engineers.

As I factored the product complexity into the set of location advantages, the national capability was the only statistically significant factor which increased as product complexity increased. Thus more complex products are more likely to be developed in countries with higher national capability.
On the relationship between firm and national capability, I found that firms with high capabilities tend to be located in correspondingly high national capability locations.

### 3.8 Summary

In this chapter, I set out to investigate a set of seven hypotheses regarding location advantage in global product development. I found that likelihood of product development developed in a country increased as its market size, number of engineering graduates and national capability increased. I also found that the likelihood of product development in a country was neither related to labor cost nor market growth rate. Additionally, I compared the average complexity corresponding with each unit of the independent variables and found that complexity only differed across national capability. Thus more complex modules are more likely to be developed in country with high national capability. Finally, I tested the relationship between national capability and firm capability, and found that the two were statistically related.

### 3.9 Contributions

I have made several contributions to the global product development literature:

- I investigated the moderating role of product complexity in driving product development to select countries around the world. Current discussions in the literature have been agnostic to product complexity in the discussion of location advantage.
- Using a negative binomial linear model accomplished two goals: Firstly, models of its type had not been used in investigating location advantage before (researchers have largely used self-assessment surveys), and secondly it allowed me to gauge the weight of each location advantage in the model.
- Combined with the rigorous statistical model, I focused on global product development instead of research and development and I was able to boil down the several location advantages in the literature into market size, national capability and number of engineering graduates.
- Finally I explicitly discussed the relationship between national capability and firm capability in global product development which had not been done before. I found that the two are closely related.
3.10 References


4 Is host-country national culture related to likelihood of product development by global parent firm?

4.1 Introduction
The relationship between national culture and product development is sparking interest among many in product development. This interest is partly driven by the increasing globalization of the product development process. For complex products, the product development process now routinely involves several countries for complex products depending on the level of product decomposition. As a result, engineers and senior leaders in product development are dealing with cultural differences on a daily basis. Given numerous other factors considered in global product development, does culture really matter in evaluating locations for developing product modules?

Global product development (GPD) is defined as a “single, coordinated, product development operation that includes distributed teams in more than one country utilizing a fully digital and connected collaborative product development process”(Eppinger & Chitkara, 2006; p. 23). By nature, global product development crosses business cultures, organizational cultures and national cultures. Culture is defined as “the collective programming of the mind which distinguishes the members of one human group from another....the interactive aggregate of common characteristics that influence a human group’s response to its environment”(Hofstede, 1984, p. 25). As Hutchins (1995) showed, problem solving happens both in people’s minds, as well in the cultural activity systems which include surrounding artifacts, conventions and routines, and Adler et al., (1986) argued “there are major differences among the cognitive processes of people from different cultures” (p. 295). Since problem solving is central to product development (Thomke & Fujimoto, 2000; Wheelwright & Clark, 1992), it is worthwhile to investigate the relationship between culture and global product development.

However, there are several levels of culture ranging from national, regional, organizational and individual, generational, to gender (Hofstede & Hofstede, 2005). From
these cultures, I am interested in national culture. Some researchers have argued that national culture has more influence on members of an organization than organizational culture (e.g., Nancy Adler & Jelinek, 1986; Oliver, 1997), while others have argued that organizational cultures are more influential than national cultures (e.g., Pothukuchi et al., 2002).

In this chapter, I take the first step towards investigating this relationship between the national culture and global product development. Studying large American companies, I investigate whether there are any correlations between the likelihood of product development done by (or for) American companies in a country, and the country’s cultural distance from the US. My findings are grounded in an analysis of 118 system modules developed by (or for) 18 leading American companies in 24 countries, and over 80 interviews with global product development leaders.

4.1.1 Structure of this chapter
Section 4.2 reviews literature as close to national culture and global product development as possible since there has been very limited work on the intersection of the two. Section 4.3 discusses hypotheses, and Section 4.4 covers the research design and research methods. Section 4.5 covers the results while Section 4.6 discusses the results and their implications.

4.2 Literature review
As mentioned above, there is a dearth of literature specific to national culture and product development. Nakata & Sivakumar’s (1996) theoretical paper in which they proposed a set of hypotheses on the relationship between national culture and product development is one of the few contributions that specifically related national culture and product development. As a result, I will review contributions which have examined the relationship between organizational functions as close to product development as possible and national culture.

4.2.1 Related findings on national culture
Unlike the previous chapters where I heavily relied on the international research and development research, the role of national culture has been largely researched in
multinational corporations’ research. Researchers have investigated how managerial decision making and leadership styles, human resources practices, marketing, modes of entry and performance, vary as influenced by national culture. Each of these is reviewed below.

4.2.1.1 Management and leadership styles
A significant amount of contributions to the multinational corporations’ literature has examined how national culture influences managerial decision making and leadership styles (e.g., House et al., 2002). They found that some elements of leadership and management vary by culture while others do not. For instance, while comparing China, Taiwan, Hong Kong and Singapore, Shenkar & Ronen (1987) found that the four countries were similar on despising individual glorification. However, when they compared emphasis on autonomy in the same set of four countries, they found that China placed more emphasis on autonomy than the other three.

Lee et al.,(2000) went beyond documenting the difference and investigated the impact of elements of national culture in product development performance while comparing the United States and South Korea. They found that authority concentration led to success in the United but not necessarily in Korea. However, they also found that top management support and project manager’s skill led to success both in the United States and South Korea.

The similarities in management and leadership styles across countries are often explained by common technological imperatives, industrial logic and global institutions (Child & Tayeb, 1983; Levitt, 1983), while the differences are often explained as driven by national culture (House et al., 2002). The former argue that a dominant mode of operating in the business environment exists while the later argue that there are many effective ways of managing and succeeding depending on the cultural contingencies. For example, Lee et al.,(2000) explained the observed different impact of authority concentration on product development success in the United States and South Korea as driven by high individualism in the US vs. high collectivism in Korea. Individualism pertains to “societies in which the ties between individuals are loose: everyone is
expected to look after himself or herself and his or her immediate family.” (Hofstede & Hofstede, 2005; p. 76). Collectivism pertains to “societies in which people from birth onward are integrated into strong cohesive in-groups, which throughout people’s lifetimes continue to protect them in exchange for unquestioning loyalty” (ibid)

Thus similarities and differences in tasks compared across countries are driven by the balance between the forces of divergence and forces of convergence in that particular task. However, more recent work has been sympathetic to the differences across cultures school of thought. For instance, Shane (1994a) found that management in different countries had different ways of championing innovations. He found that some innovation decisions in Taiwan were required to go through the hierarchy or high-level managers, while the same decisions were not required to go through hierarchy in the UK (p. 33). In negotiations, Adler & Graham (1989) found that the way people interacted intra-culturally was different from the way they interacted cross-culturally in negotiation. They also found that people’s negotiations tactics were driven by their national cultures.

4.2.1.2 Human resources practices
Researchers have also investigated the similarities or differences in human resource management practices of affiliates in foreign countries. They found that human resources practices often followed local practices depending on the extent of local inputs, method of founding, presence of expatriates, and extent of communication with parent firm (Rosenzweig & Nohria, 1994, p. 229). Likewise, Bae et al., (1998) found differences in human resources practices between firms hosted in Taiwan and those hosted in Korea suggesting a role for location institutions in shaping human resource practices.

4.2.1.3 Marketing
As one would expect, culture plays an important role in consumption patterns and marketing (Soares et al., 2007), and the marketing organizational function exhibits the most differences across nations. For instance, Dawar et al., (1996) found that power distance and uncertainty avoidance influence consumers’ product information search but not tendencies to share the information which are important for adoption and brand choice (p. 497); and van Everdingen & Waarts (2003) found that national culture
influenced the adoption rates when investigating the adoption of ERP systems across 10
European countries. They found that countries associated with higher uncertainty
avoidance and low long-term orientation were less likely to adopt innovations instantly
than countries in northern Europe. Uncertainty avoidance is defined as “the extent to
which the members of a culture feel threatened by ambiguous or unknown
situations” (Hofstede & Hofstede, 2005; p. 167). Long-term orientation is associated with
“the fostering of virtues oriented towards future rewards – in particular perseverance and
thrift, while short-term orientation fosters virtues related to the past and present – in
particular respect for tradition, preservation of face and fulfilling social
obligations” (Hofstede & Hofstede, 2005; p. 210)

4.2.1.4 Modes of entry and performance
In addition to management, human resource and marketing, extensive research has been
done studying the relationship between national culture and entry mode into foreign
countries. This stream of research yielded conflicting results. On one hand, Kogut &
Singh (1988) and Erramilli & Rao (1993) found that firms preferred forming joint
ventures as the cultural distance of the host country increased. On the other hand, Shane
(1994b) and Erramilli et al., (1997) found that firms preferred wholly owned modes of
entry as cultural distance of the host country increased. Brouthers & Brouthers, (2001)
reconciled the results and showed that “investment risk in the target market moderates the
impact of cultural distance on mode selection. Managers select more cooperative modes
of entry in low investment risk markets, but select wholly owned modes of entry in high
investment risk markets” (p. 185).

Finally, in comparing performance of joint ventures set up by firms from Western and
Oriental cultures in China, Li et al., (2001) found that “similar culture was not always the
most valuable resource affecting firm performance (measured as return on assets)” (p.
128). They argued that technology played a more prominent role in influencing
performance compared with culture.
4.3 Hypotheses
Rosenzweig (1994) observed that human resources practices of a MultiNational Corporation (MNC) embody local practices depending on external variables such as the amount of communication with the parent firm. He found that marketing and manufacturing embody local practices to a lesser degree than the finance function. Likewise, some elements of product development are bound to vary by region while others do not. Some of this variation might be beneficial to product development, while some might not.

The distributed teams stream of research has investigated the challenges associated with teams that cross national culture which might be detrimental or beneficial to product development. For instance, Ohara-Devereaux et al. (1994) argue that differences in cultures can take a toll on global product development. Using case studies of Americans working with Canadians, Chinese and Mexicans; they investigated how time zones and culture affected relations at work. They first divided culture into language, context (elements that surround and give meaning to a communication event – in high context communication, meaning is highly colored by relationships, history and status (p. 50)), information flow (how messages between people and organizational levels (ibid)), power and equality, and time orientation (monochromic vs. polychromic). They found that context affected the overlap between business and social relationship, information flow affected the packaging of information in business meetings, power and equality influenced the amount of direction employees expected from leaders and time orientation affected agendas and lead times.

Cramton (2001) added the difficulty of maintaining mutual knowledge among team members distributed across cultures to the list of challenges associated with global product development. Because communicating parties do not know exactly what type of knowledge they share, communication tends to be much more difficult than in local product development. Olson and Olson (2000) also added that it is difficult to build trust in global projects compared to local projects and this makes coordination among the tasks more difficult as well.
Given all the internal team dynamics exemplified above, I am predominantly interested in scrutinizing whether national culture is related to the likelihood that product will eventually be located in a particular host country. I hypothesize that people are most comfortable working with others as close to their cultures as possible, thus as the cultural distance increases, the likelihood of product development in that country would decrease:

H1: As a nation’s cultural distance increases, the likelihood of product development in that host nation decreases.

In measuring performance, Li et al., (2001) found that technology was a more significant performance driver than culture. Brouthers & Brouthers, (2001) found that investment risk was a more important driver than culture, and in human resources, Rosenzweig & Nohria (1994) found that the similarities in practices was moderated by other factors such as communication with the parent firm. Along the same lines, I hypothesize that the significance of culture is moderated by product complexity; thus firms will get any capable firm to develop complex modules despite their national culture.

H2: In the case of highly complex products, national cultural distance is not related to the likelihood of product development in the host nation

4.3.1 Operationalizing culture
As an “aggregate of common” (Hofstede, 1984; p. 25) culture is difficult to capture for analysis in quantitative scholarly work. The difficult of studying culture is further compounded by the fact that “culturally normed behavior and patterns of socialization could often stem from a mix of religious beliefs, economic and political exigencies and so on. Sorting these out in a clear-cut fashion would be extremely difficult, if not totally impossible” (Sekaran, 1983 p. 68).

However, Hofstede & Hofstede (2005), Schwartz (1994) and House et al., (2004) have made prominent contributions attempting to understand and quantify culture at the national level. Hofstede & Hofstede’s (2005) study is currently the most widely used
cultural framework in scholarly research (Kirkman et al., 2006). For instance it is used in management (e.g., Kogut & Singh, 1988), marketing (e.g., Deshpande & Webster, 1989), and work related attitudes (e.g., Bochner & Hesketh, 1994). Hofstede (1984) used 116,000 questionnaires sent to 88,000 IBM employees in 72 countries, and came up with the dimensions of national culture summarized in Table 4.1:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Distance</td>
<td>The extent to which the less powerful members of institutions and organizations within a country expect and accept that power is distributed unequally (p. 46)</td>
</tr>
<tr>
<td></td>
<td>For example, Arab countries are higher than the US on the power distance index.</td>
</tr>
<tr>
<td>Individualism Index</td>
<td>The extent to which individuals are integrated into group. In individualistic cultures, ties between individuals are loose; everyone is expected to look after himself or herself as her immediate family. In collectivist culture, people are integrated into strong cohesive in-groups. For example, the US is higher on the individualism index than China.</td>
</tr>
<tr>
<td>Long-term Orientation</td>
<td>The fostering of virtues oriented towards future rewards - in particular, perseverance and thrift, while short-term orientation stands for fostering of virtues related to the past and present (p. 210) For example, Japan is higher on the long term orientation index than the US.</td>
</tr>
<tr>
<td>Masculinity</td>
<td>A society is called masculine when the emotional gender roles are clearly distinct; men are supposed to be assertive, tough and focused on material success whereas women are supposed to be modest, tender and concerned with quality of life. A society is called feminine if the gender roles overlap; e.g., both men and women concerned about quality of life issues (p. 120) For example, the US is higher than Sweden on the masculinity index.</td>
</tr>
<tr>
<td>Uncertainty Avoidance</td>
<td>Uncertainty avoidance is the extent to which the members of a culture feel threatened by ambiguous or unknown situations (p. 167) For instance the US is higher than Germany on the uncertainty avoidance index.</td>
</tr>
</tbody>
</table>

In this research, Hofstede & Hofstede’s (2005) cultural dimensions are particularly attractive because they were derived from a fairly technical environment. Schwartz (1994) derived his framework from a survey of high school students and their teachers. House et al. (2004) derived his framework from middle managers across a variety of industries such as the food industry and the telecommunications industry. Additionally, the validity of the Hofstede’s dimensions has been corroborated with “six major replication studies, each covering at least 14 countries” (Hofstede & Hofstede, 2005; p. 6), and several smaller studies. The framework is also the most robust given its large sample size (Soares et al., 2007). Thus it is a prudent decision for us to operationalize culture using Hofstede & Hofstede’s (2005) five dimensions of culture.

Critics of Hofstede & Hofstede (2005) often argue that culture can not be captured by “trivial” four (later five) dimensions (McSweeney, 2002), and that the dimensions were
derived from one organization hence they can not represent an entire society (Sivakumar & Nakata, 2001). While the first argument does not help scholarly dialogue, the second works in my favor as I discussed above. Other critics argue that culture is changing and heterogeneous within any country. Since I am analyzing national cultures, the heterogeneousness within a country does not confound my analysis. Hofstede (1984) himself argued that his framework was suitable for studies at the country level.

4.3.2 Operationalizing product development
I operationalize product development as the amount of modules from my sample developed in the specified country.

4.4 Research design
The research protocol consists of two major phases. The first phase is largely exploratory and qualitative while the second phase is quantitative. The qualitative methods allowed us to “capture a more complete, holistic, and contextual portrayal of the units under study” (Jick, 1979; p. 603), while the second phase focused on the quantitative methods as a way of systematically analyzing hunches, anecdotes and quotes from the qualitative findings.

4.4.1 Phase I: Exploratory research
The goal in this phase was to understand culture in its holistic context. As mentioned above, national culture is fairly difficult to quantitatively capture hence it was necessary for us to investigate culture through emersion and qualitative interviews. As part of the data collection process described in the previous chapters, I asked respondents open ended questions about culture and its role in globally distributed product development.

4.4.1.1 Phase I: Case selection process
The population consisted of product development leaders who had worked or were working in globally distributed product development projects. The population included leaders working on medical equipment such as magnetic resonance imaging machines, industrial equipment such as earth-moving equipment, electronic equipment such as servers, etc. From that population, I used stratified quota sampling and interviewed product development leaders working at large American companies with the goal of
increasing the diversity of opinions in my sample. In order to avoid generalized superfluous discussions, my interviews were grounded in experiences around modules developed outside the program home-country and the processes involved.

The first case study was company A (a large Fortune 10 American company), where I spent 500 hours as a global product development engineer on a clean-energy, high-tech globally distributed product development project that involved four companies in three countries across Europe and North America. In the spirit of quota sampling, I then broadened my cases to chief technology officers, directors and vice presidents of engineering at 17 other companies involved in the development of electromechanical systems. These 17 companies were chosen to test the replicability of findings from the initial case study.

4.4.1.2 Phase I: Data collection process

The data collection process began with open-ended interviews around culture and other factors described in Chapters 2 and Chapter 3. Each interview was done and recorded in person, and lasted anywhere from 30 minutes to 3 hours depending on the seniority of the interviewee and stage in the research process. The average interview lasted for an hour. The interviews tended to be longer during the early phases of the research. As the responses converged, I used semi-structured interviews which tended to be shorter. The interview data were supplemented by observation data as I worked on a globally distributed product development project for 500 hours.

Most of the product development leaders were located in the US and a few were located in Europe and Asia though they all worked for American companies. All in all, I conducted 80 interviews from 18 different large American companies over a period of 15 months in addition to the initial 500 hours spent in the field as a global product development engineer.
4.4.2 Phase II: Multiple embedded case studies
Our over-arching goal during this second phase was to obtain quantitative data for statistical analysis with the goal of correlating cultural distance and amount of product development.

4.4.2.1 Phase II: Case selection process
There were two populations during this phase of the research: the country and the module populations. Similar to Pisano (1990), the country population consisted of the top 50 countries that trade with the US in electromechanical systems. The modules population consisted of tier one electromechanical modules developed by large American firms outside the program home-country. Once again, I used the quota sampling strategy for gathering modules. Beyond the first case study, I limited each company to at most 12 modules.

4.4.2.2 Phase II: Data collection processes
Because I used two populations for the model, I will describe how I obtained data from each of the populations.

4.4.2.2.1 Country-level data collection process
I collected the list of countries for the study from the United Nations Commodity Trade Database (UNcomtrade, 2008) using the Harmonized System 2002 codes 85 and 87. I chose the top 50 based on the value of exports to the US (i.e. imports by the US from those countries). From the 50 countries, 25 did not develop any modules from my samples hence I dropped them from the analysis. With the list of countries in hand, I gathered the cultural dimensions of each country from Hofstede & Hofstede (2005).

4.4.2.2.2 Module-level data collection process
The module data collection process was partially combined with qualitative data gathering described above. After establishing contact at the company, I set up a phone or in person conversation with the product development leader. At the beginning of each interaction, I described the two phases of the research. I then spent most of the time having qualitative discussion about global product development as described above, and reserved some time at the end where I explained the data that I needed to measure the module complexity.
Once they understood the data requirements, I gave the respondents a week to fill out the rest of the data template. In addition to the template, I gave them a document (see Appendix A) which explained each column of data to serve as a reference. Most respondents returned the data template within a couple of days. All in all, I collected data on 156 modules developed in 25 countries from 18 companies. For more details on how I collected module level data, please see Chapter 2.

4.5 Analysis and results

4.5.1 National cultural distance
I adopted Kogut & Singh’s (1988) definition of cultural distance as shown in Equation 4-1:

Equation 4-1: Definition of cultural distance

\[ \text{Culture}_j - \text{distance} = \sum_{i=1}^{5} \left( \frac{(I_{ij} - I_{uu})^2}{V_i} \right) / 5 \]

Where:
- \( I_j \) is Hofstede’s index for country \( j \).
  - \( i = \text{Power Distance, Individualism, Masculinity, Uncertainty Avoidance and Long Term Orientation as defined in Table 4.1} \)
- \( V_i = \text{variance of index } i \)

Thus cultural distance is the average of the variance-weighted, squared difference between a specified country’s index value and the US value of that same index

4.5.2 Quantitative hypotheses tests
Figure 4.1 is a scatter plot of partial regression plots of the number of modules developed in each of 22 countries versus the national cultural distance of each country. Findings from Chapter 3 indicated that firms are drawn to countries with high market size, number of engineers and national capability. As result, I controlled for these variables in plotting Figure 4.1. From the initial list of 25 countries which developed modules in the sample, I dropped the US because it is the reference country and Canada because its Hofstede Indices are not available. I also dropped Taiwan because it is not recognized as a country
by the US, hence I could not measure its national capability (see chapter 3) using data from UNComtrade.

Figure 4.1: Partial regression plot of number of modules and cultural distance

In Figure 4.2 I normalized the complexity of modules in the study, and treated modules whose normalized complexity is above 1 as “complex modules.” Both figures do not visually indicate any relationship between the amount of modules developed in a country and the cultural distance of that country from the US.
However, I statistically tested for any relationship between cultural distance and product development by testing the significance of partial correlations (Garson, 2008c). Since firms are drawn to firms with large market size, number of engineering graduates and national capability, I controlled for these variables in the partial correlations. For details on how I measured these variables, please see Chapter 3.

Partial correlation results are shown in Table 4.2. As a result, I reject hypothesis 1 but cannot reject hypothesis 2 since both partial correlations are low and not statistically significant. This means that host national culture does not affect where product development is eventually located in the context of electromechanical systems. However, the results do not contradict the conjectured trend that correlations are even weaker when I consider the most complex half of modules in the analysis.
Table 4.2: Partial correlations of culture distance and global product development

Partial correlations of Number of Modules and Culture Distance

Control Variables: Market Size and National Capability, Number of Engineering Graduates

<table>
<thead>
<tr>
<th></th>
<th>Number of Modules</th>
<th>Number of Highly Complex Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation with Culture Distance</td>
<td>-0.15</td>
<td>-0.12</td>
</tr>
<tr>
<td>Significance (2 tailed)</td>
<td>0.54</td>
<td>0.62</td>
</tr>
<tr>
<td>df</td>
<td>17</td>
<td>17</td>
</tr>
</tbody>
</table>
4.5.3 Qualitative corroboration

During the qualitative phase of the research, interviewees often brought up culture as an important variable in global product development. I coded their statements to examine whether culture is an issue in global product development. For instance, one engineer mentioned “there are more cultural differences with Asian cultures, and that makes it a little harder,” and I coded his statement as *culture is an issue*. “However,” the engineer continued, “culture is very forgiving.” I coded this last portion of his statement as *cultural issues can be overcome*. Most of the responses fell into this format where respondents indicated that there were cultural differences which posed challenges though engineers overcome the challenges by extended exposure to other cultures and/or training. Additional examples include:

- a manager who routinely worked with the Japanese and Scottish who said, “cultural differences make the process less efficient.... [however] face to face events help us get over them [cultural issues]”
- a German supplier stationed at one of the manufacturers mentioned: “those [cultural] misunderstandings cause friction and friction is loss. The good news is that you can plan for that. My experience is that only brand new people complain about that. If they are there [the same job] for two or three years, they understand why”
- a supervisor mentioned “Lack of awareness of cultural differences is the biggest issue....[however] there is no big impact”
- another director added, “culture plays into the initial phase until we know each other and trust each other,”

A tally of these and other responses is shown in Figure 4.3 below.

Nonetheless, some respondents did not see cultural differences as easily resolved, especially in the context of *decision making*. One such director summarized his thoughts: “There are multiple components of the cultural problems. Some of them react to training and practice. Some of them are systemic and remain.” He went on to illustrate his point using an example where transcending cultural differences is harder: “In a Swedish team, the team has the decision power, and the leader facilitates the team. In a Japanese team....they are concerned about not embarrassing people and saving face and [they
have] a whole series of processes, which are alien to a Western person on the team. Somehow, they share all the data and drive very hard to optimize solutions. In a Western team, management will dictate where the team is going, possible or not...the whole concept is stretch..." I coded his response as *culture is an issue* which is not easily overcome.

Additionally, a couple of respondents did not find culture to be an issue at all. These were people who had been developing products globally for a long time, and some who were not born in the US but had been working in the US for a long time.

**Figure 4.3: A tally of statements on cultural issues in global product development**

![Bar chart showing frequencies of cultural issues](chart.png)

### 4.6 Conclusion and discussion

The findings from this research and the literature cited suggest that national culture matters in product development. However, it does not influence the likelihood of product development in a host country, irrespective of the product complexity. Thus product development leaders develop modules in any country irrespective of its cultural distance.
As shown in Chapter 3, product development leaders choose countries with high market sizes, number of engineers and national capability.

Given that interviewees illustrated cultural challenges using examples that could easily be traced to the individual national culture indices, I tested the significance of correlations between the individual national culture dimensions and amount of modules developed in the host country. Most correlations were less than 0.5. Excerpt for the masculinity index, all correlations were not statistically significant. Masculinity addresses the division of gender roles in a society, and since there is a hardly a logical causal link between masculinity and product development, I conjectured that the correlation was spurious.

People generally adapt and work through many of the initial challenges associated with cultural differences. The product development leaders in my study often cited the uncertainty avoidance of the Japanese as an example. “When the Japanese say they will do it, they will do it. US suppliers are not as committed” Working through this cultural difference is a question of knowing the other engineer’s point of view. One supervisor identified power distance difference between the US and Sweden “They [Swedes] also push their responsibilities very low,” and another identified the power distance difference between the US and Philippines in the opposite direction “they usually don’t say no to the boss, I had to keep everyone from lunch until they had challenged my plan at some point.” These are all cultural differences which can be overcome through acclimatization.

4.7 Contributions
My main contribution in this chapter has been investigating the impact of host national cultural on the likelihood of product development by an American parent firm. Very little empirical work has been done on this topic before irrespective of the adopted point view. In product development, and international research and development, researchers have often ignored host firm culture in scholarly dialogue. In multinational corporations’ research, researchers have often ignored the product development function. In distributed teams’ research, researchers have generally not gone beyond team dynamics in investigating the role of national culture in global product development.
I also went beyond the first level of analysis and investigated whether product complexity influences the role of national culture in global product development. Similar to most contributions in this dissertation, the role of complexity has not been investigated before.

4.8 Future research
Since this research showed that people often overcome cultural differences, further contributions to the understanding of national culture in global product development might document the cost of working through the cultural differences. Time and resources spent working through cultural differences could be spent improving other aspects of the global product development process. Thus enabling practitioners to weigh the cost and benefit of cultural differences might improve the global product development process.

Further work could also be done documenting and investigating the impact of the systemic cultural differences, which can not easily be overcome, on product cost, performance and quality.

Finally, additional research could be done investigating whether national culture influences the location decisions of companies with different national origins. For instance, the Japanese culture is fairly homogenous compared to the American culture. Thus it would be informative to investigate whether national cultural distance influences the likelihood of product development for Japanese parent firms as compared to American firms.
4.9 References


123


5 Characterizing leading Global Product Development organizations and their coordination practices

5.1 Introduction
In today's flat world, leading American firms are increasingly globalizing their product development operations. Despite the challenges inherent in such processes, firms are globalizing product development efforts primarily to get access to markets and unique regional capabilities. For instance, firms are increasing product development operations in China for the access to a growing regional expertise in electronics, and the large growing market. In this chapter, I identify features that characterize global product development organizations, and discuss their recommended practices.

My primary motivation is to describe global product development (GPD) organization and categorize lessons learned in GPD into groups that allow product development leaders to better develop products globally. These lessons were gathered from over 80 extensive interviews with product development leaders from 18 leading American firms over 15 months. I spent the first 500 hours of the 15 months as a global product development engineer on a high-tech, clean-energy, global product development effort involving four companies across Europe and North America. Companies in the study include Caterpillar, Otis, Philips Medical Devices, CISCO, Analog Devices, Boston Scientific, Dell and Ford (full list of companies is shown in Table 3.1). In addition to these interviews, I analyzed data on the development processes of 118 products developed by (or for) American companies across 25 countries in Asia, Europe and the Middle East.

Case studies discussed in this study are diverse ranging from industrial equipment, through medical equipment to electronics. While some companies in these three sectors (particularly in the electronics industry) are well on their way to realizing benefits associated with global product development, most are still working on establishing robust processes and creating requisite capabilities. As a result, my findings are useful to
companies with full fledged global product development efforts and those developing the capability as well.

5.1.1 Structure of this chapter
Section 5.2 reviews the literature as it applies to product development. Since my goal is to characterize the organization and identify recommended practices, this section indentifies the appropriate views of the organization. Section 5.3 discusses the research protocol, while Section 5.4 discusses the results. Section 5.5 discusses implications of findings and section 5.6 lists references.

5.2 Literature review
There are several useful views of an organization such as the human resources view (Drucker, 1954; Mintzberg, 1983), the resource based view (Penrose, 1959; Wernerfelt, 1995), and the information processing view (Galbraith, 1973; March & Simon, 1958; Tushman & Nadler, 1978). From these, the information processing view has proven fruitful as a way of understanding the product development organization (Clark & Fujimoto, 1991; Cusumano & Nobeoka, 1990). This view focuses on describing the product development organization through strategy, structure and process perspectives. However, the globally distributed product development organization spans several countries and national cultures have a non-negligible imprint on the organization and organizational processes (Hofstede & Hofstede, 2005; House et al., 2004; Ohara-Devereaux & Johansen, 1994). As result, I will add the people view to my investigation of the global product development organization.

5.2.1 Product development operational strategy
The product development strategy is driven by choice of market and approach to product differentiation (Clark et al., 1987). In essence, product development strategy is “a plan for technology and a plan for product-market position” (Wheelwright & Clark, 1992; p. 33). Since “research on technology strategy will never produce the definitive recipe for success.....strategy research [has focused] on how to learn and change capabilities” (De Meyer & Loch, 2008; p. 28). Benefits associated with learning in the general global context are well documented in the literature (e.g. Doz et al., 2001). In this chapter, I will focus on learning in the context of product development. Researchers have divided such
strategic learning into learning the “know-why” and “know-how”. Know-why is the deep understanding of science and scientific research, while know-how includes the capability to create, produce, market and deliver products (Wheelwright & Clark, 1992; p. 36). Thus as I characterize the leading global product development organization and gather recommended practices, I will investigate whether firms are predominantly learning the know-why or the know-how. Additionally, I will collect some of the practices that they are employing to maximize this learning process.

Under the market strategy portion of the globally distributed product development strategy, researchers have examined technology evolution, competition, customer and availability of resources. Combining these together, I am interested in understanding the positioning of globally developed products in regional and global markets. I will investigate whether products were predominantly sold in the region in which they were developed or sold back to the rest of world. This understanding has important implications for the product development process.

5.2.2 Product development organizational structure
Structure is largely concerned with the internal organization, and the location of decision making power in the globally distributed product development organization (Galbraith et al., 2002). In general, the right structure for an organization depends on the environment (Thompson, 1967), and there are both formal and informal structures in organizations. The formal organizational structure implies assignment of individuals to groups, boundaries and scope of work for the groups. The informal organizational structures are determined by the actual communication ties that emerge among people in the organization (Sosa & Mihm, 2008; p. 165). This section is dedicated to the formal organizational structure, and the informal structure is covered under the processes portion of the study.

5.2.2.1 Formal structure
Functional and project organizational structures are the two extreme ends of formal organizational structures. However, most organizations lie on the continuum (Ulrich & Eppinger, 2004). The functional organization is organized around disciplines or functions,
while the project organization is organized around the project (Allen, 1977). The lightweight project organization is closer to the functional organization, and has a junior manager coordinating project activities while the key decisions are made by the functional managers (Wheelwright & Clark, 1992). Members reside in their home functions, but are assigned to the project coordination team. The heavyweight organization is closer to the project organization. Project managers tend to be senior and have primary authority over their direct reports (Wheelwright & Clark, 1992).

As mentioned above, my goal is to describe whether the programs in the study have functional or project-based organization structures.

5.2.3 Product development organizational processes
In general, organizational processes are centered on decision making, problem solving, and information processing and sharing (March & Simon, 1958). At the product development level, key variables for decision making and information sharing include the degree of overlap in development stages, coordination among functions and phases, and coordination among and within projects (Cusumano & Nobeoka, 1990). These processes can also be viewed as the way through which problem solving cycles in product development are linked (Wheelwright & Clark, 1992). The need for coordinating processes arise from interdependence in the development of complex electro-mechanical systems (Eppinger et al., 1994; Simon, 1962) mitigated by attempts to modularize the electro-mechanical systems (Baldwin & Clark, 2000) and/or modularize the organizations (Sanchez & Mahoney, 1996).

As documented in the social networks literature, the informal organizational processes contribute towards success in global product development. For example, researchers have investigated the importance of sparseness (Burt, 1992; Granovetter, 1973) and cohesion (Coleman, 1990) in communication in organizations. Sparseness is best suited to bringing in new ideas while cohesion is desired during the implementation phases (Makumbe, 2006). In globally distributed product development, sparseness is a given that face to face communication decreases with distance (Allen, 1977).
As a result there are several communication media that managers use to boost communication because more communication is generally associated with increased performance (Ahuja, 2000; Eisenhardt & Tabrizi, 1995). For example, Sosa et al (2002) investigated the role of time zones and cultural differences on the communication media in globally distributed product development operations. They found that use of the telephone increases with distance as a substitute for face to face communication and decreases with increasing difference in time zones. The use of email increases with both geographic and cultural distance.

The prevalence of IT systems for coordination is taken as a given in the design of highly complex electro-mechanical systems. According to Anderson et al.(2008) coordination can be improved by:

- Improved management coordination practices
- Redesigning incentives
- Employing supplemental mechanism such as boundary spanners

My goal for this section is to document the processes and practices that fall into these categories.

5.2.4 People

The people dimension has largely been ignored in product development research. However, as Trent & Monczka (2005) found in their study of global sourcing, access to qualified personnel with the right skills, knowledge and capabilities is critical for success in global product development. Extensive work has been done in trying to understand distributed teams (Gibson & Cohen, 2003; Hinds & Kiesler, 2002) and some of this research has focused on global product development teams(e.g. Mohrman et al., 2003).

This stream of work greatly improved my understanding of product development teams. However, an understanding of individuals within their national culture context adds to our understanding of globally distributed product development. Not only do global outsourcing and global partnerships cross organizational boundaries, they also cross national boundaries. As Hutchins (1995) showed, problem solving (central to product
development) happens both in people’s minds, as well in the cultural systems such as surrounding artifacts, conventions and routines.

Given the paucity of literature in this area, my goal is to gather a set of characteristics of people who excel in global product development.

5.2.5 Literature summary
The literature highlights the three views of the organization based on the information processing view of the organization. These views are namely the strategy, structure, and process views of the organization. Given that the global product development organization crosses several cultures, I added the people view to the organization in an attempt to understand the characteristics of people who excel in global product development.

5.3 Research protocol
Since my goal in this chapter is to characterize leading development organizations, I employed grounded theory (Glaser & Strauss, 1967) and exploratory (Stebbins, 2001) research methods. The grounded theory helped in identifying the important constructs for further investigation while the exploratory results allowed me to investigate the frequency with which the constructs and practices were mentioned during the interviews.

5.3.1 Research design
The research population consisted of product development leaders who had recently globally developed or were globally developing complex electro-mechanical systems such as magnetic resonance imaging machines, earth moving equipment, electronic equipment such as servers, and elevator systems. From that population, I used quota sampling and interviewed product development leaders working at large American companies with the goal of increasing the diversity of opinions in the sample. In order to avoid generalized superfluous discussions, the interviews were centered on products developed outside the program home-country.

Initially, I spent the first 500 hours as a global product development engineer on a clean-energy, high-tech globally distributed product development project that involved four
companies in three countries in Europe and North America. In the spirit of quota sampling, I broadened my interviewees to chief technology officers, directors and vice presidents of engineering from 17 other companies involved in the development of electro-mechanical systems after completing the first case study. These 17 were chosen to test the generalizability and replicability of findings from the initial case study.

5.3.2 Data collection process
The data collection process began with open-ended interviews on various aspects of product development including recommended practices and lessons learned in global product development. Each interview was done and recorded in person, and lasted from 30 minutes to 3 hours depending on the seniority of the interviewee and stage in the research process. The average interview lasted for an hour. The interviews tended to be longer during the early phases of the research, and as the responses converged, I used semi-structured interviews which tended to be shorter. The interview data was supplemented by observation data as I worked on the globally distributed product development project for 500 hours.

Most of the product development leaders were located in the US and a few were located in Europe and Asia though they all worked for American companies. All in all I conducted over 80 interviews from 18 different large American companies over a period of 15 months including the initial work experience.

5.4 Analysis and results
In this section, I present findings on the characterization of leading global product development organizations. I first discuss the product development operational strategy, and then the organizational structure. This is followed by a discussion of management and coordination processes, and I end the section with a discussion of the characteristics of successful people in global product development. Table 5.1 lists the ranks of the interviewees in the study.
Table 5.1: Interviewees and their ranks

<table>
<thead>
<tr>
<th>Interviewee rank</th>
<th>Number of interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Vice Presidents / Chief Technology Officers</td>
<td>3</td>
</tr>
<tr>
<td>Vice Presidents</td>
<td>3</td>
</tr>
<tr>
<td>Directors</td>
<td>19</td>
</tr>
<tr>
<td>Chief Engineers / General Managers</td>
<td>5</td>
</tr>
<tr>
<td>Managers</td>
<td>11</td>
</tr>
<tr>
<td>Supervisors</td>
<td>14</td>
</tr>
<tr>
<td>Engineers</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80</strong></td>
</tr>
</tbody>
</table>

Though I did not explicitly measure success in terms of the typical product development metrics such as cost, performance and schedule, there are several indicators of successful programs versus their less successful counter parts. Firstly, the study contains companies that are globally developing products well by most measure. These include Caterpillar, Otis, and Phillips Medical Devices etc. Secondly, people have a tendency to provide examples that paint them in positive light, thus by asking for lessons learnt and recommended practices, there is a high likelihood that I obtained practices that have contributed to success in these companies. Finally, some practices were enthusiastically described in the affirmative while others were not. By comparing the two, we get a sense of which practices worked well and which did not.

5.4.1 Results: product development operational strategy

From the 118 modules, I ran statistical models testing the relationship between market size, market growth rate, national capability, labor cost and amount of engineering graduates from each destination country with the likelihood of product development in that host country. From these models, I found that more products were developed in countries with high market size, high national capability and high number of engineering graduates. In general, the market size was the most important factor in influencing the likelihood of product development in a country. When I introduced product complexity as a moderating variable, I found that only national capability increased as complexity increased. Thus complex products are more likely to be developed in counties with higher
national capability. The likelihood of product development was operationalized as the number of modules developed in the specified country.

To further understand the technology portion of the strategy I investigated whether firms predominantly acquired technology (know-why), product development process or systems knowledge (know-how) or both when they globalized product development operations. A tally of the responses is shown in Figure 5.1.

**Figure 5.1: Results on technology strategy: Know-why, know-how or both**

From a capability point of view, firms in this sample were predominantly driven by the quest for technology vs. product development know-how when they globalized product development. None of the product development leaders from the sample were driven by the quest for process know-how on its own, and about a third of the program leaders indicated that their programs were driven by both technological know-why and process know-how. In critical cases where offshore entities lacked the process know-how, parent firms often trained their key suppliers or partners. As one engineer put it “we had to train
them on Failure Modes Effects and Analysis,” and a manager added “some suppliers
don’t have automotive background, [in such cases] we help the companies develop
automotive systems capability.”

This training in product development process know-how has several advantages. Firstly,
it increases efficiency in product development operations, which contributes towards
timely delivery of prototypes and products. Secondly, the product development process
training increases process commonality between the host and the parent firm, which in
turn improves coordination among the firms involved.

In emerging markets, both technological and process capability tends to be limited hence
parent firms invest in training their global counterparts. To protect these investments,
firms acquire small stakes in such suppliers as a way of avoiding hold-ups, and
potentially profiting from sharing their technology. As one director revealed “we are
growing capability in Guangzhou....because they will be an important market,” and a
manager from a separate firm added “we avoid hostage situations by funding them [the
suppliers], so that we have rights to the technology”

Given that parent firms increase their access to unique technologies by engaging global
partners, global suppliers or captive offshoring, I gathered a set of practices used to
maximize learning from these global counterparts. Different product development leaders
had responses as varied as creating global centers of excellence, sharing best practices,
training the locals to take over as part of the organization and hiring the best and brightest.
However, most product development leaders emphasized staff exchange programs as one
way of maximizing learning in global product development. These exchange programs
are discussed in detail below (see Sections 5.4.3.3.2 and 5.4.3.3.3).

The other portion of product development strategy addresses product market positioning.
I investigated whether products developed globally were predominantly sold globally
with local offices providing customer support, predominantly sold in the region in which
the products were developed or sold in a separate foreign region. For instance, I wanted
to find out whether products developed in Southern Europe were predominantly sold throughout the entire world, sold in Southern Europe, or sold in a foreign region such as North America.

**Figure 5.2 : Product positioning strategy**

Figure 5.2 shows that most products developed globally were sold globally, allowing for regional customization. However, the number of product development leaders whose products were sold in the local region was also significant. Selling globally while allowing local customization implies a model in which the core of a product is similar around the world, while selling regionally implies a model in which most of the product is different around the world. These regional differences are driven by safety, environmental regulations, local tastes or aesthetics.

Product development leaders whose products were developed in one region and predominantly sold in another region were rare. In such instances, globalization decisions
were largely driven by capacity constraints. Only a very small fraction of the global product development efforts were driven by capacity constraints.

5.4.2 Results: Organizational structure

Most formal organizations in the study had a formal matrix structure consisting of functional leadership from the headquarters and regional leadership from the different regions. To minimize confusion and overlap of responsibilities, the global leadership was ultimately responsible for product development. They allocated resources to captive offshore locations, and set bonuses for the captive offshore workforce in consultation with the captive offshore leadership. Such a structure enhanced coordination compared to structures where there were no clear lines of authority. As one manager said, “you do not want people reporting to two different people at the same level, you need a clear structure, preferably reporting to one person, so that a common set of assumptions and responsibilities can be diffused into the organization.”

However, the formal organizational structures leaned towards the functional or project structures to varying degrees. I will describe the two extreme cases: one organization which strongly leaned towards the functional structure and another which strongly leaned towards the project structure. In general, structures supporting novel technologies tended to be more function than project oriented, while structures supporting older technologies were more project than function oriented. I conjecture this is because with new technology, competitive advantage lies in developing a functioning product hence having a group of capable engineers together is likely to lead towards that end than having other functions at high levels in the product development organization. On the other hand competitive advantage is driven by other factors besides technology in the case of products predominantly utilizing older technology. Thus one is likely to observe the project oriented organization in those organizations since the other organizational functions play a more prominent role.

We gauged the extent to which the product development organization leaned towards one structure versus the other by the composition of the most senior design review board. For the most function-leaning organization, the design review board consisted of engineering
leadership from countries most involved in the product development project. For instance, one director described the review board as consisting of at least two engineering managers from different locations, one from the EU and the other from North America. Other organizational functions such as purchasing were represented on the board at junior levels, and more distant functions were represented on an adhoc basis.

The most project-leaning structure had a completely different design review board. The board consisted of rotating senior marketing and sales leaders from the targeted regional markets, and a permanent set of product development leaders from the headquarters. Though meetings were chaired by the product development leaders, other organizational functions had prominent and senior roles.

5.4.3 Results: Organizational processes
My goal in this section is to document practices that firms were using to coordinate global product development. I divided these practices into three: redesigned incentives, management coordination practices, and supplemental coordination activities.

5.4.3.1 Redesigned incentives
Though the literature describes redesigned incentives as a form of coordinating and motivating employees towards desired goals, I only observed such practices at one organization. In that particular organization, incentives, such as bonuses, were awarded by the regional managers before the prominence of global efforts in the organization. As globalization became strategically important, and management sought ways of building allegiance to the global organization vs. the local organization, they redesigned the incentive structure so that bonuses were awarded by the global managers in consultation with the regional managers.

The scarcity of instances in which the incentive structures changed was unexpected. It is possible that some organizations had incentives structures that accounted for the globalness of the product development in place already, or that some organizations did not change their incentive structures at all. I believe it is more of the later than the former.
Nonetheless, the organizations rewarded global behavior in subtle ways. For instance, many titles included the term “global” e.g. the Global Director of Engineering vs. Director of Engineering. Senior leadership in many organizations had global experience, which increased global awareness among their subordinates. Additionally, some organizations earmarked a certain percentage of modules to be developed in emerging markets. Other organizations moved key executives to India and China as a way of engaging the two countries at a senior level.

5.4.3.2 Management coordination practices
The managers in the study employed a variety of practices that enabled coordination in globally distributed organizations. Figure 5.3 shows a tally of these practices.

Figure 5.3 : Management coordination practices

5.4.3.2.1 Creating common processes
At a very high level, all organizations employed one common global product development process. This global process aligned communication throughout the organization as members knew what at each stage gate along the global product development process. However, the global product development process had to be more
robust than a product development process largely used locally. This need for robustness was driven by the limited time for live or face to face meetings needed to augment a loosely defined process. Moreover, people work in different social and business cultures; hence they are prone to interpreting the process differently. As one chief technology officer mentioned, “[there is] need to have a robust process compared to when product development is local. It has to be well defined, well understood, and less prone to human error.”

However, having a common and robust global product development process did not necessarily translate into common ways of feeding into that process. The high level product development process set goals, but did not describe subprocesses for meeting those goals. As an illustration, a high level global product development process might stipulate: “Have module simulations done 20 weeks from project the kick-off date,” and more or less leave the details of how to meet that goal to the individuals. From the sample of companies in the study, organizations which did not specify the subprocess had more coordination challenges than organizations that did. The companies with smoother coordination processes had all engineers trained on the subprocesses and tools for meeting requirements at each stage gate in the same way. Based on the interviews with directors of engineering, it was not enough to have common tools; the processes of using the tools needed to be the same as well. These common subprocesses increased efficiency in coordination across the different modules and across different phases of the product development process. They served as an accumulation of lessons learned and best practices hence they boosted chances of success.

In some cases I found that disparity in tools and subprocesses was driven by legacy systems, regional prominence of different software vendors and internal champions with a “not invented here” mentality. In those organizations, the coordination was a little fractured. One chief engineer succinctly summarized his sentiment as: “the tools and processes need to be common (or seamless) otherwise we might as well FedEx the engineering drawings and the product will be done sooner than working across some of these systems.”
In order to achieve this subprocess commonality, organizations often employed different strategies depending on whether they were dealing with a captive offshore, a global partner or a global supplier. Equal partners were the most difficult to influence because they often had their own systems. Additionally, they were potential competition hence both sides were vested in keeping some processes proprietary. Captive offshore sites of equal significance in the global organization were challenging as well because they sometimes had their own legacy systems. Smaller captive offshore sites tended to be easier to influence. Because of their size, the cost of replacing legacy systems tended to be manageable. Key suppliers developing strategically important modules were easier to influence, especially when the parent firm was the biggest supplier’s customer. Because the majority of organizations in the study are behemoths in their industries, suppliers often bent backwards to meet their requirements. Thus organizations in the study often imposed their product development process knowledge and systems on their key suppliers. As another chief technology officer pointed out, “sometimes it’s quicker to get things done with a supplier because they are more likely to do what we want on time.”

5.4.3.2 Aligning and clarifying objectives
There were two elements to clearly aligned objectives in global product development. The first was that objectives had to be the same at different levels in the organization, and the second was that the way people understood those objectives had to be understood by the entire team.

In general, strategic objectives tended to be the same in the study. However, disparity in objectives and goals surfaced at the operational level. Such disparities were often resolved through compromises in face to face meetings.

The second form of disparity rose from the way people communicated and responded to objectives as driven by their cultures. Several managers illustrated this cultural aspect using Japanese and American teams. Here is how one director summed up his thoughts: “In a Western team, management will [drive] where the team is going, possible or not since the whole concept is stretch. [One] could stretch the team with a 130% target
improvement, and it will be very good if the team improves by 120%. That’s totally counter-cultural to a Japanese leader, who will absolutely commit hara-kiri and fall on his sword rather than sign up to a target he can’t deliver.” Thus good managers were cognizant of these differences and factored them into the way they interacted with their teams.

Aligned objectives had an added advantage which was emphasized by the leaders that I interviewed. It allowed engineers to solve problems on their own without having to consult leadership up the hierarchy in a different country. Another director of engineering illustrated: “…the reduced communication [compared to teams in the same building], can generate lots of missteps and problems. If there is really good strategic alignment, the problems can be dealt with quickly just between two people. If it’s the traditional, customer, vendor relationship, it has to go up and down the hierarchy in order to solve a problem. Because of the 12 hour time difference, language barrier and the working style differences, it might take a long time to solve that problem. Somebody would have to raise that to his management, then raise it over to us… and you are already 36 hours behind [when] you have just heard that you have a problem. It will take another 36 hours to set up a meeting and another 36 hours to solve that problem”

5.4.3.2.3 Making fewer assumptions and checking progress
Because of the difference in cultures and languages, most leadership emphasized the need for modularizing not only the product, but the process as well so that they could check progress more routinely instead of making assumptions. From my work, I found two drivers for this phenomenon. The first is that the same words have different meanings in different parts of the world, especially when people are using their second or third languages. For instance, one German engineering supervisor working in the US mentioned: “everyone besides North America [the project did not include England] is forced to speak in a foreign language and this can lead to misunderstanding. For instance, if somebody wants to have something the next day and says “I could use it tomorrow.” If you translate this word by word into German, it means “yeah, it won’t be too bad if I could get it by tomorrow, but it’s not necessary that I get it tomorrow… [What he really means is that], I must have it. Period.”

141
The second driver is national culture. In some cultures, people avoid bringing bad news to their superiors. Those that avoid bad news might paint a rosy picture with the hopes of closing the gap before the global boss flies across the world to check progress. One engineer illustrated: “In one case, we sent someone over there to see the completed factory, but there was a hole on the ground. We needed to have [our] personnel on the ground or see photographs to make sure that the plant was being built.” Thus product development leaders advise modularizing the tasks in order to better check progress.

5.4.3.2.4 Creating a collaborative structure
Product development leaders in my study also emphasized the need for a collaborative structure in global product development. They emphasized the need for a single project manager instead of two managers in different locations or clear structure where lines of authority are clearly drawn between the regional and the functional leadership.

In order to strengthen collaboration through the informal structure overlaid on the formal structure, engineering leaders emphasized the need for stable assignments because of the difficulty associated with rebuilding personal relationships across the globe.

5.4.3.2.5 Knowing your team
Some product development leaders also emphasized knowing the team as a key to successful coordination in global product development. This is easier said than done in the global context (Mortensen & Hinds, 2001). An in depth knowledge of the team, which people normally get around the water-cooler, often lacks in the global context. Having that knowledge allows the leadership to assign tasks to the right people. When asked for key lessons learnt in handling complexity in global product development, one vice president replied “be aware of the strengths of the teams around you. Know the people”

5.4.3.2.6 Planning upfront extensively
Extensive upfront planning is critical in the context of global product development. This is because opportunities for spontaneous meetings are limited by the time zones and expenses involved in getting people together for live discussions. According to one
manager, “...we need formal planning for at least two months [for suppliers, or partners abroad], but I don’t need as much forward-looking planning with local suppliers”

Additionally, extensive upfront planning lays out a structure for the entire process which clarifies responsibilities going forward and improves the coordination process.

5.4.3.3 Supplemental coordination mechanisms
In addition to the management coordination practices above, organizations also employed supplemental coordination mechanisms. This section describes the prominent supplemental coordination mechanisms.

Figure 5.4: Supplemental coordination mechanisms

5.4.3.3.1 Face to face events
Face to face events allow engineers to build trust, share tacit knowledge and create a common working culture. Product development leaders emphasized the importance of having these events at the beginning of the product development process so that people can build trust and personal relationships. Because of the limited travel budget, some companies had a tendency to minimize the amount of face to face events. However, as
one director of engineering argued, “the travel cost is very low compared to the cost of
developing a working prototype. Blowing up a prototype costs [the equivalent] of 20 trips
across the ocean.” Another director added: “You can’t underestimate the importance of
face to face communication. Despite all the tools and these enablers, the fact is that the
most progress is made in face to face interactions.” “Having such face to face events at
the beginning improves efficiency by 30% to 40%,” concluded another engineering
director.

Face to face events allowed people to build trust and communicate better. Trust allowed
people to solve problems independently, and allowed people to understand each other
when they communicated over email or phone. The respondents believed these personal
relationships were very important. “There is a need for real human relationship. We need
to have the trust first, and then we can do routine meetings. Individuals in the company
can solve problems much more quickly if they have personal relationships.”

The frequency of these face to face events differed across companies. Some emphasized
face to face events at the program launch and meeting when necessary afterwards, while
others emphasized routinely meeting at face to face events every quarter. The face to face
events were hosted at different companies on a rotating basis.

5.4.3.3.2 Stationed boundary spanners
Stationed boundary spanners are employees on exchange at other-entity sites in the global
product development effort. The duration of each stay ranged from three months for
people flown in from India to the US at one company, to a couple of years for German
engineers flown into the US at another company.

Stationed boundary spanners allowed the organizations to better serve the internal or
external customer. They allowed companies to understand the reasoning beyond simple
design requirements which strengthened the relationship among the entities involved in
the development project. As one supplier stationed at the parent firm’s site argued, “as a
supplier, it’s always good to understand why the customer is asking that question….if
you understand why he wants it, how his internal processes work, and how the documents
he needs tie together then its easier to serve him better.” Likewise, the parent firms also sent members of their organizations to key suppliers: “We have people in Germany reporting to us here in the US. I communicate with them on a daily basis, though they are physically at the supplier’s site.”

For companies struggling to send work to emerging markets, they found that once engineers had worked with somebody on an exchange program, they built trust and were more willing to send some work to their counterparts in emerging markets.

5.4.3.3 Travelling boundary spanners
Travelling boundary spanners are engineers involved in the project who travel between sites without necessarily spending an extensive amount of time at the other-entity sites. These boundary spanners were extremely common across the different programs and companies in my study. The duration of the stays ranged from a couple of days to a couple of weeks.

Travelling boundary spanners often had a “fire-fighting mission” compared to stationed boundary spanners. “We can share engineering analysis; you can see interference between parts, and vehicle simulation easily. The physics of the vehicle are the same in Belgium as in Massachusetts. However, we need face to face meetings during program management, problem resolution, quality issues, investigations and diagnosis of problems. For instance say your system is shutting down, and you don’t know why it’s shutting down; ability to communicate with people and share ideas in real time greatly helps in resolving the issue.”

5.4.3.4 Local presence
Local (same country) presence served two related roles: minimizing risk and improving coordination among the firms involved in the product development effort.

Local presence was particularly important during the development of new products. Having a US presence meant that the parent firms could easily and cheaply visit their supplier’s / partners’ site. More importantly, it meant that the suppliers had a better understanding of US rules and regulations specific to the industry. Product development
leaders in the medical devices industry emphasized the need for a supplier or partner with local presence partly because the industry is heavily regulated by the FDA. In such cases, the strategic intent of the parent is to develop the products in the US and have the supplier bear the risk of moving the capability abroad: “One of the things that we look for is how to mitigate our risk, and one of the ways that we can do so (this is not always the case) is to find a company that has US presence. We can develop our products using their US presence, and then have them move that capability”

Product development leaders in this study also emphasized local presence as an important way to ensure coordination and learning among the different sites. During the system integration phase of product development, companies pushed to have engineers from suppliers at the integration site in order to handle any integration issues that might arise.

Larger suppliers often had a US presence, while smaller suppliers often “rented-a-rep” by engaging a local American supplier to act as their representative in the US.

5.4.3.3.5 Information systems
Information systems were used by most companies and programs in the study. The associated “number of times mentioned” in Figure 5.4 is not as high as one would expect because engineers took the information systems for granted. However, most respondents emphasized the need to have common or seamless information systems. As one chief engineer puts it: “In some cases, the use of different tools is a barrier. You need world class information systems that are easy to use since you cannot send everybody over there [abroad]. The tools have to be common or seamless at their interfaces. Processes have to be common, and the people have to be trained in similar ways. For example, say we are operating in an IDEAs CAD environment and my partner in Britain in CATIA, the translation from one system to the other is a disaster.”
5.4.4 Results: People

Finally, I sought to understand the characteristics of people who excel in globally distributed product development. Figure 5.5 shows these characteristics as uncovered from the interviews.

Figure 5.5: Characteristics of people successful in GPD

5.4.4.1 Communicate well

Ability to communicate well is critical in global product development. People come from different cultures; have different norms, different languages, and different business practices which must be handled in order to ensure communication as driven by the interrelated nature of product development. In addition, there is very limited time for face to face or live meetings because of geographical and time zone differences.

To overcome these challenges, product development leaders emphasized the need for both, formal and informal communication. In formal communication, the communicators need a good understanding of the process, tools and objectives. Having common tools
that everyone uses greatly simplifies the communication process. In addition to having a
good knowledge of the material being discussed, managers emphasized the need for
structured communication. “The meetings times are fewer when people are in different
time zones, therefore you got to plan the communications a lot more carefully. Because
you interact with the guy less frequently, more information has to pass between people in
a short amount of time. It has to be structured (objective and topics) and language has be
very clear.”

Informal communication is the equivalent of the water cooler chat. Product development
managers found that adding water-cooler chat to their formal communication very useful.
They argue that such communication might not be directly related to the task at hand, but
it adds to a sense of belonging to the team and has often yielded tangible results when
something deemed not important at one time became important later in the process.

5.4.4.1.2 Flexible
There were two forms of flexibility deemed critical in global product development:
flexibility from a logistics point of view, and flexibility from an open-mindedness point
of view.

Logistic flexibility is desired as a response to several challenges in global product
development such as different time zones. For instance, interviewees emphasized the
need to be flexible in terms of time worked. This flexibility allows people to hold
meetings outside the normal working hours. However the inconvenience needs to be
borne by both sides. Many interviewees did not feel that it was productive to consistently
have one team work early or late while the other worked during the normal hours.

Flexibility in the form of open-mindedness was a response to differences in cultures and
differences in ways that people work. Because of different cultures, people have different
approaches to problem solving, and being flexible allows teams to utilize the best
elements of their diverse cultures for effective product development. As one systems
integration director put it: “take the open and creative mindedness of American engineers,
combine that with extreme attention to detail of Northern Europeans and with the speed of the Chinese, and you have a very good team”

5.4.4.1.3 Other characteristics
In addition to the characteristics mentioned above, respondents mentioned the need for people who take initiative in order to be successful in global product development. This is critical since engineers working on the same project are literally continents apart. To keep projects moving, people need to take initiative. People also need to be organized, and quick to respond in order to be successful in global product development.

5.5 Discussion and conclusion
In this chapter, I characterized the globally distributed product development organization, and discussed some recommended practices in coordination. From a strategy point of view, I found that firms were globalizing primarily to get access to markets, large pools of labor, and capability. Within capability, firms were predominantly interested in technological capability vs. process capability. Additionally, I found that products developed globally were either predominantly sold globally or sold in the region in which they were developed. These findings imply that there are two main models of global product development: one where the products have a similar core and unique regional features and one where the bulk of the products are unique and specific to regions.

The organization structures were predominantly matrix in nature, and the functional leadership at the headquarters tended to have the upper hand when lines of authority were blurred. I was surprised to find that very few firms had significantly changed their incentive structure as they globalized their product development.

From a people point of view, the most desired characteristics in engineers working globally was the ability to communicate well and the capacity to be flexible. Communicating well required mixing both formal and informal communication while flexibility was in the form of flexibility to difficult logistics and flexibility to other cultures and ways of doing business.
Additionally, I documented several practices that firms are using to ensure coordination, and bring the organization strewn around the globe together. I categorized these under management practices and supplemental mechanisms. Management practices included creating more robust processes and subprocesses, modularizing not only the product but the process as well to create opportunity for checking whether communicated messages were understood as intended, extensive upfront planning, and regular face to face events. Supplemental mechanism included different kinds of boundary spanners and state-of-the-art common or seamless information technology systems.
5.6 References


6 Overall summary and discussion
The goal of this dissertation has been to investigate the role of complexity in global product development. I did so using four semi-independent studies:

In the first study, I investigated role of the product nature in the type of relationship between entities in global product development. I operationalized nature of the product using product characteristics namely, complexity, specificity, strategic importance and designing firm’s capability. I operationalized the type of the relationship as one of the three modes of global product development namely, developing a product with a global partner in a foreign country, developing own a product in a foreign country or developing a product through a supplier in a foreign country.

In the second study, I investigated how complexity influences the location choice in global product development. I first indentified location advantages (reasons why firms develop products in locations that they do) in global product development and examined the moderating role of product complexity. I also explored the relationship between national capability and firm capability.

In the third study, I examined whether host national culture affected the likelihood that products will be developed in a particular country. I operationalized national culture using Hofstede’s (1984) cultural indices and the likelihood of product development as the number of modules from my sample developed in a country.

In the fourth and final study, I investigated the characterization of global product development organization, and garnered some recommended practices currently employed by firms in the study.

The findings from these investigations are summarized and discussed below. Structurally, I will present and discuss a set of findings before moving on to the next set of findings.
6.1.1 Role of complexity in modes of global product development

With the module as the unit of analysis, I investigated the significance of module complexity, specificity, strategic importance and requisite designer’s capability in influencing the mode of global product development given the three modes: captive offshoring, global outsourcing or global partnerships.

As part of the research methods, I gathered 156 modules using quota sampling from 18 leading American companies over a period of 15 months. I included industrial companies such as Honeywell, medical device companies such as Philips Medical Devices and electronics companies such as CISCO. For analytical methodology, I used multinomial logistic models with the mode of global product development as the dependent variable, and module characteristics as independent variables. I conducted three sets of analyses: the first pooled data from all regions of the world (i.e. worldwide analysis), the second focused on modules developed in mature regions such as Germany and Sweden (mature regions analysis), and the final focused on modules developed in emerging regions such as China and India (emerging regions analysis).

From the worldwide analysis, I found that the more complex modules were likely to be developed through global partnerships; modules of medium complexity were more likely to be developed in captive offshored facilities and the least complex modules were likely to be globally outsourced. The complexity-driven differences in likelihoods among the three modes is highest in emerging regions and least (statistically non-significant) in mature regions. However, the difference in likelihood between captive offshore and global partnership is smaller (statistically non-significant) than the difference between captive offshore and global outsource in both worldwide and in emerging regions.

This finding is different from an extension of the prevailing thinking that complex work is done in-house (e.g. Novak & Eppinger, 2001). In the global setting, the prevailing thinking would imply that complex modules were likely to be captive offshored. I found that complex modules were more likely to be developed through global partnerships than
they were likely to be captive offshored though the difference between the two was statically significant.

I believe this difference is due to the fact that firms often seek technology not available locally when they globalize product development, particularly to regions with higher capability. Since complexity is a combination of parts, interactions, and technological novelty, it is logical that global partnerships are more likely to develop the more complex products. Global partners’ technological capability tends to be higher than captive offshores’, and their capacity to coordinate is higher than global outsourcees’. Captive offshores might have better capacity to coordinate but not necessarily the better technological capability. Thus when deciding which mode of global product development to use between captive offshore and global partnership, management might consider weighing the technological difficulty vs. the coordination difficult of the product.

When I divided the world into mature and emerging regions, national capability tended to be higher in mature regions. As a result, host entities in a global product development relationship are fairly capable. Thus complexity does not differentiate among the three modes in mature regions but it does in emerging regions where national capability is lower. From the qualitative interviews, it appeared that firms were largely drawn to emerging regions for business reasons than capability reasons; hence firms would differentiate among the modes based on complexity. Global outsourcees would develop simpler modules as long as the firm finds a business presence in the emerging. However, capability in emerging regions is growing as well.

Secondly, using global outsourcing as the reference category, I found that captive offshoring was associated with lower technological capability. Similarly, I found that global partnerships were associated with lower technological capability compared to global outsource. However, when comparing captive offshore and global partnership, the global partnerships were associated with higher technological capability. Thus the technological capability “ladder” has global outsource at the top, global partnerships in “middle” and captive offshore at the bottom. This same relationship holds in both mature
regions and worldwide. However, the difference between global outsource and global partnership is not statistically significant in mature regions.

For the worldwide and mature regions, these two findings are intuitive if one assumes that firms are partly driven to globalize by the quest for better technological capability. Since all the firms in the sample are headquartered in America, most of their technological talent is currently located in the US implying that captive offshores tend to have less technological capability. Thus global partners and global outsourcers would have better technological capability than captive offshores. However, this trend is changing because firms are developing centers of excellence around the globe. For instance, the captive offshore in China might be developed as the electronics center of excellence for the entire global enterprise or the Australian captive offshore developed as the mining equipment center of excellence for the entire global enterprise.

In emerging regions, technological capability is barely related to modes of global product development because its p-value is 0.08. However, I found that captive offshores were associated with the higher technological capability compared to global partnerships as is typical in the literature (e.g. Prahalad & Hammel, 1990). The low statistical significance might be partially explained by the low number of modules (40) developed in emerging regions. As described in the research methods section, I did not restrict the country-origin of the modules, as long as they were developed outside the program home-country.

Thirdly, the more specific modules were either captive offshored or developed through global partnerships, while the least specific modules were globally outsourced. The same relationship holds in mature regions and specificity was not statistically significant in emerging regions. Overall, the difference between global outsource and captive offshore was conventional. However, my findings on the difference between global partnership and captive offshore were in contrast to the manufacturing literature. I found that specificity is practically the same between captive offshore and global partnership. In their work, Montverde & Teece (1982) used a binary model i.e. a module was either manufactured by a supplier or manufactured in house. They found that specific modules
were manufactured in-house even though they had different degradations indicating whether a module was manufactured by the OEM.

Finally, my findings on module strategic importance are similar to the current thinking in the literature (e.g. Venkatesan, 1992) though I have extended the phenomena from manufacturing to product development and added the global dimension to modes of product development. I found that firms captive offshored the modules that they deemed strategically important in all regions. However, I was surprised to find that global outsourcers and global partnerships were developing modules deemed of equal importance to the strategy of the parent firm. One would have thought that global partners would develop modules of more strategic importance. Perhaps today’s global partners can be tomorrow’s competition; hence firms jealously safeguard modules at the core of their products. This is especially the case where intellectual property protection is limited.

Figure 6.1 is a pictorial summary of these findings. In a nutshell, the study showed that module complexity, specificity, designing firm’s capability and strategic importance were all related to the modes of global product development, and the level of importance varied by region.
The managerial implications of this work include helping product development leaders decide on the suitable modes of global product development given product characteristics. For instances, I have shown that complex modules are likely to be developed through partnership. Thus product development leadership faced with that decision might consider developing complex modules through partnerships.
6.1.2 Role of complexity in global product development location advantage

With the country as the unit of analysis, I investigated the influence of product complexity in the product development location choice. I broke down the research into three parts: The first involved sieving through location advantages in the literature and applying rigorous statistical tests to find factors critical in global product development. In the second part I introduced product complexity into the analysis to probe for changes in significance of the location advantages. In the third and final part, I investigated the relationship between national capability and firm capability.

The research method consisted of two phases. During the first phase I reduced the set of key location advantages garnered from the literature into a handful using grounded theory and exploratory qualitative research. In the second phase, I collected country characteristics (i.e., candidate location advantages) of the top 50 (by value) countries that trade with the US in electro-mechanical systems. These characteristics included the number of modules (from chapter two) that were developed in that country, market size, national capability, number of engineering graduates etc. For analytical methods, I used a negative binomial linear model with the number of modules developed in a given country as the dependent variable and country characteristics as independent variables. I also used the Brown-Forsythe robust test of the equality of means for the complexity analysis and Pearson chi-squared test of independence for the capability analysis.

I found that firms were drawn to locations with high market size, large pools of engineers and high national capability, and my findings generally match what some researchers have found in international research and development (e.g. Kumar, 2001).

However, I was able to take these findings further and weigh the influence of each independent variable using standardized coefficients from the generalized linear model. In general, I found that the market size was the most important location advantage. This finding supports my conjecture that global product development is closer to the end user than research and development; hence the market size plays a critical role. However, it
was surprising to find that the market growth rate was not a statistically significant location advantage. The product of market size and market growth rate was highly correlated with the market size; hence I statistically could not differentiate between the two except by using findings from qualitative interviews. These findings indicated the market size was the key location advantage.

The number of engineers was the second most important location advantage, while the national capability was the third most important location advantage. In the light of findings from the qualitative portion of the research that firms build capability if they deemed a region important, these statistical findings make sense.

I also found that labor cost was not a statistically significant location advantage in the context of global product development. In the case of China and India, the two countries are producing a significant number of engineers, but those engineers are not as qualified as the engineers produced in the US according to Wadhwa et al (2007). Farrell et al (2005) of the McKinsey Global Institute found that only 13% of the engineers from China and India would be suitable to do the high level engineering work in the US. According to the qualitative interviews, competition for the top engineers is stiff and firms tend to pay more to keep the most qualified engineers. Firms also give the qualified engineers more interesting work instead of mundane development tasks as was the case during the beginning of the globalization of product development. Additionally, I analyzed the relationship between engineering wages and manufacturing wages from my dataset and found that engineering wage differentials across countries were smaller than manufacturing wage differentials.

However, as I factored the product complexity into the set of location advantages, the national capability was the only statistically significant factor which increased as product complexity increased. Thus more complex products are more likely to be developed in countries with higher national capability.
On the relationship between firm and national capability, I found that firms with high capabilities tend to be located in correspondingly high national capability countries. Thus choosing one is statistically not different from choosing the other.

From an organizational strategy point of view, these findings help organizations decide on countries to locate product development as part of their global product development operations. At a country level, the findings have implications about what countries might do to attract product development. For instance, countries might develop centers of excellence as a way of attracting product development. For instance Ballad (the largest fuel cell producer) moved from Arizona to Vancouver because the Canadian government was providing incentive for fuel cell technology.

6.1.3 Relationship between host-country national culture and likelihood of product development by American parent firm

In the fourth chapter, I investigated the relationship between host-country national culture and the likelihood of product development. Operationalizing likelihood of product development as the number of modules in the sample developed in a country, I examined the relationship between national culture and the likelihood of product development. I also investigated the moderating role of complexity by investigating the relationship between national culture and likelihood of product development using complex modules i.e. modules whose complexity was above the sample average complexity.

Similar to the chapter on location advantage, the research method consisted of two phases. The first phase focused on understanding culture through qualitative discussions with global product engineers and their management. The second phase was focused on getting data for statistical analysis. I gathered the number of modules (from chapter two) developed in a country, and then I gathered the cultural dimensions of each of the countries in which modules were developed. These are namely, power distance index, masculinity, individualism, uncertainty avoidance and long term orientation. For analytical methods, I used partial correlations with variables identified in chapter two as control variables.
The statistical analysis i.e. partial correlations between amount of modules developed in a country and national cultural distance, showed that culture does not influence the likelihood of product development in a host country. As shown in Chapter 3, the likelihood of product development in a country is influenced by the market size, number of engineer and national capability.

The analysis of the qualitative interviews showed supporting results. The respondents indicated that culture was an issue in global product development. However, people generally adapt and work through many of the initial challenges associated with cultural differences though there are some systemic cultural differences which remain.

The managerial implications of this chapter include encouraging management to institute cultural exchanges programs that allow cultural acclimatization. Thus, management should not be dissuaded from engaging countries with different cultures but rather seek countries with large market size, national capability and number of engineers.

6.1.4 Characterizing leading Global Product Development organizations and their coordination best practice

In chapter five, I characterized the global product development organization as viewed through the information processing view, i.e., its strategy, structure and processes. Since global product development organizations cross business and national cultures, I added the people view to these three views. In addition to characterizing the GPD organization, I collected practices which have worked well for companies in the study.

In terms of research methods, I used grounded theory and exploratory research. All in all, I interviewed 80 product development leaders from 18 leading American companies such as Caterpillar, CISCO, Otis, Phillips Medical Devices, John Deere, Ford and Boston Scientific over a period of 15 months. I spent the first 500 hours of these 15 months as a global product development engineer on an environmentally-friendly and high-tech, globally distributed product development project involving four companies in three countries across the Europe and North America.
I found that products developed globally were either sold around the globe with local customization or sold in the region in which they were developed. Additionally, firms were globalizing largely for the know-why (technological) capability vs. know-how (process or systems) capability. Additionally, the formal organizations were largely matrix in structure.

There were several recommended coordination practices. Management practices included creating more robust processes and subprocesses, extensive upfront planning, regular face to face events and modularizing, not only the product but the process as well, in order to create opportunities for close-loop monitoring to ensure that design requirements were understood as intended. Supplemental coordination mechanisms included different kinds of boundary spanners and state-of-the-art, common or seamless information technology systems. Under the people view, the product development leaders in the study emphasized the capacity to be flexible, and the ability to communicate given the different cultures, norms, languages and business practices, as critical factors for success.

6.2 Limitations

Modules in the study were gathered through quota sampling. Thus findings can not be generalized too widely. However, I gathered data from 18 different companies from three different groups i.e. industrials, electronics and medical device groups. These three groups can be characterized at an abstract level, and findings might have implications for industries that share that same abstract characterization (Yin, 2002).

The second limitation is that most of the modules in the study came from the industrial and medical device fields. Thus the methodologies for measuring variables are most applicable to electromechanical systems, and not necessarily electronic systems.

Finally, the modes analysis used multinomial logistics model whose coefficients are not intuitively easy to understood. Perhaps there is a way to reduce the data and use analytical methodologies easily understood by many in the community.
6.3 Opportunities for further contributions

From a modes of global product development point of view, further contributions can be made by investigating how other product characteristics influence modes of global product development. For instance, the impact of uncertainty or opportunism associated with the product is not investigated in this work. Thus one could investigate whether there are tendencies to captive offshore modules associated with high uncertainty or opportunism.

Investigating the role of manufacturing in global product development provides opportunities for contribution as well. Since the first wave of globalization was in manufacturing, manufacturing might play an important role in global product development. For instance, research could be done investigating whether current offshore manufactures are likely to do the product development as well.

Another opportunity lies in investigating the characteristics of modules which are globally developed versus the ones that are locally developed. Similar work has been done in global manufacturing, but no such work has been done in global product development.

From a location advantage point of view, areas of further enquiry include the relationship between national capability and firm capability. I have only scratched the surfaces by showing that the two are statistically related. This work could be extended and yield results on how the governments can work together with firms in the country to boost the likelihood of having products developed in the country. Some work has been done in this research area from an organization point of view. However, we have not seen any research which approaches the subject from a technology or product point of view.

Finally, I only investigated module-specific global product development. Phase-specific global product development i.e. global product development in which the phases of the product development process are globalized as compared to the product modules, is fairly common in the field. Hence research can be done investigating when firms decided to
globalize the phase of product development versus the module development. Preliminary observations from this study indicate that as firms mature in global product development, they emphasize module-specific global product development. One question is why?
6.4 References


7 All references


8 Appendix A: Module-level data collection template

Document explaining each data item in the module-level data collection template (reformatted)

<table>
<thead>
<tr>
<th>Data Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the module developed abroad</td>
</tr>
<tr>
<td>Name of the developer</td>
</tr>
<tr>
<td>Country</td>
</tr>
<tr>
<td>The type of global product development employment</td>
</tr>
<tr>
<td>Technological novelty of the module</td>
</tr>
<tr>
<td>The importance of having UTC design module to UTC’s strategy</td>
</tr>
<tr>
<td>The product development capability of the module developer</td>
</tr>
<tr>
<td>Are UTC-owned product development facilities present in the country</td>
</tr>
<tr>
<td>The number of parts in the module</td>
</tr>
<tr>
<td>Number of platforms supported by module</td>
</tr>
<tr>
<td>Number of relationships with other module designers that required frequent communication because of design interdependence</td>
</tr>
<tr>
<td>Percentage of parts-count that are off-the-shelf</td>
</tr>
</tbody>
</table>
The amount of effort that I expended coordinating module suppliers who had a design role - what (if anything) did the company due to coordinate suppliers to the module
9 Appendix B: Definition of statistical terms

Heteroskedasticity – means the variation in the dependent variable is large for some values of the independent variable than for others (Albright et al., 2004). Independent variables such as market size and the number of engineers exhibited heteroskedasticity. Taking the number of engineers as an example countries on the left are fairly small and have little variation. As the number of engineers increases (to the right), there is more variation as shown in Figure 9.1. More formally, I used the Levine test to find out whether variables were heteroskedastic or not.

Figure 9.1: Illustration of heteroskedasticity

Brown and Forsythe’s F test of equality of means is more robust than ANOVA used to test the equality of means when deviations from the mean are highly skewed. The test does not assume homogeneity of variances (Garson, 2008d). I used it to test the difference in average module complexity as the market size increased because the deviation from the mean market size increases as market size increases.
Negative binomial model – The negative binomial model is classified as one of many generalized linear models. The generalized linear models are so named because they allow one to specify the distribution function of the dependent variable, and the link function. Thus they are more general compared to ordinary least squares models which assume that the dependant variable is normally distributed. In this chapter 2, the dependent variable most closely matched the negative binomial distribution as shown in Table 3.8.

The negative binomial model is similar to the Poisson distribution but used when the variance is larger than the mean. In this particular case, there are many countries which did not develop any modules from the initial list of 50; hence the mean is less than the variance.

Pearson chi-squared test – Chi-squared test tests whether counts from the rows in a table are probabilistically independent of counts from the columns (Albright et al., 2004). It compares the observed values to expected values assuming independence, and independence hypothesis is rejected if the difference between the two is large enough.

Partial correlation - Partial correlations are correlations between variables while controlling for other variables.